

## THE EXTREME PROPERTIES OF MATTER\*

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WE know a great deal about many of the fundamental properties of matter, and our knowledge enables us to assign limitations on its qualities; so that whereas improvements in materials are possible, we can assign limits beyond which it is fairly certain that these improvements cannot go. It is proposed here to examine some of the principal limitations of this kind. It is only possible to deal with a few of the chief ones, and the list will include the mechanical properties of solids, liquids and gases and some of their electric and magnetic properties.

### Strength of Materials

We know a good deal by now about the forces which act between atoms. There are several rather different types of force which occur in various types of solids, and the type which concerns us here is the metallic one, since in considering the strength of materials we obviously turn first to the metals. The basic structure of a metal is a crystal, usually of one of the simplest and most symmetrical classes. In this crystal the atoms have each one or more electrons set free, and these wander about freely as a sort of cloud. This cloud of negative electricity acts as a sort of cement holding together the positively charged atoms. In addition, these atoms exert forces on one another, partly of the repulsive electric type that would be expected, but also others of a kind the principle of which is to be mastered only by going rather deeply into quantum theory. The behaviour of these forces can be imitated by thinking of atoms as exerting attractions or repulsions on one another, but these forces need no longer conform rigorously to the pure electric type. The only character of them that I need at the moment is that they are not to vary violently with the distance; that is to say, if in equilibrium one of the forces between two adjacent atoms is so and so, then if they are displaced to a distance not greater, say, than 20 per cent, this force will not have altered by more than, say, a factor of 2.

Let us now examine what we should expect for the strength of a crystal based on this model. Consider, as the most characteristic thing in a solid, its shearing

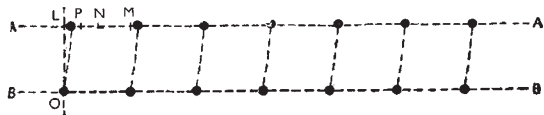


Fig. 1.

strength. Fig. 1 shows two rows of atoms, each of which is intended to represent a whole sheet of atoms standing out at right angles to the paper. The sheets are held together by their mutual atomic forces together with those coming from the atoms in the sheets above *A* and below *B* which are not shown. In the unstressed condition the atoms of *A* and *B* are supposed to be exactly opposite one another, but this is unessential to the argument; the first atom of *A* would therefore be at the point *L*. Now impose a small shear by displacing the whole sheet *A* and all above it a little to the right. A force will at once

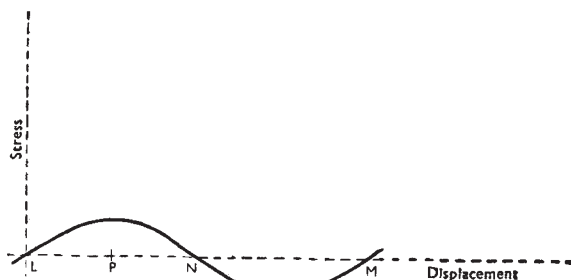


Fig. 2.

come into play resisting this displacement, and we can tell what this force is by our knowledge of the shear modulus.

We can conveniently represent what happens by making a diagram (Fig. 2) in which the stress is plotted against the displacement of the sheet of atoms *A*, and the shear modulus gives the direction of the tangent at *L*. As to what happens farther on we cannot be sure, but we do know that if the *A* sheet is bodily transplanted one atom's length along to *M*, the force will vanish again, and around this point the curve will repeat itself. Moreover, half-way between there must be another point of equilibrium, and this must be unstable, because it lies between two points of stable equilibrium. This will be represented by the point *N* and a tangent sloping the other way. We do not know how to complete this curve, but we can make very useful conjectures about it. From all reasonable assumptions about the atomic forces being continuously variable with the distance between the atoms, we may say that the curve should have a reasonably smooth form. The simplest one to take is a sine curve, so we will adopt that. We know the slope at *L*, and the position of *N*, and from these it is elementary to calculate the height to which the curve rises at the point *P* one quarter way along from *O* to *M*. This will give the maximum stress that the metal can stand without yielding. An elementary calculation shows that this stress is  $G/2\pi$ , where  $G$  denotes the shear modulus. For a good steel the value of  $G$  is about 6,000 tons per square inch, and this suggests a shear strength of about 1,000 tons per square inch, in contrast to 10 tons per square inch, which is roughly the actual value.

The argument I have given suggests that a crystal of a metal ought to be very much stronger than it is; roughly it ought to be possible, without breaking, to shear a cube until it formed a parallelogram with angles given by the slope of *OP* in Fig. 1, that is to say, more than  $10^\circ$  off the right angle. This is completely contrary to the facts, for when a single large crystal is made of a pure metal it is found to be as soft as putty. This difficulty has been much considered, and I may refer to work of G. I. Taylor, who attributed the hardness that working gives the metal to 'centres of dislocation', that is, to imperfections in the ordering of the crystal, an effect which is practically universal in crystals. It would be out of place to go into his theory, but it confirms the point that to get a strong piece of metal one must have small crystals in it, not large ones.

If one examined the experimental facts without recourse to theory, one would conclude that it is the irregular junctions between crystals that make its strength, and that the metal is a sort of foam of these irregularities containing in its bubbles the putty-like crystals. But this is not a possible view, since we

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have to face the difficulty that those bubbles ought to be much stronger, by our previous argument, than the foam material between them. Moreover, there is an even greater difficulty in accepting such a view, because we know, at least roughly, the magnitudes of the atomic forces, and from them we can calculate what the shear modulus should be, and the answer comes out about right. Thus the crystals ought to be much stronger than the intercrystalline irregularities; and yet the more of these irregularities there are the stronger the metal becomes. We seem to be in the paradoxical position that a chain is strengthened by multiplying the number of its weakest links.

Some recent ideas of Bragg and others have done much to clear up the situation. In the model I took of the sheared crystal, I imagined the atoms on each sheet rigidly held together in relatively fixed positions. In fact, however, they are not fixed, since temperature dictates that atoms can never be at rest. Each atom is oscillating all the time in an irregular manner about its average position, and this makes possible a re-adjustment among the atoms without calling into play the strong stresses which would arise if the whole sheet had to be displaced like a rigid body. Consider the matter in more detail. A piece of metal is now to be regarded as composed of a large number of small crystals, all differently oriented and held together by a cement of irregularly placed atoms. When one of the blocks of crystal several layers thick is sheared a little, the displacements of the atoms (more strictly, now, of the average positions of the atoms) will call into play reactive forces which provide the shearing stress. But if the shear is made larger a new possibility occurs, which is that a slip should occur between the two rows. On account of the heat motions of the atoms this may now occur without calling into play the violent reactions that our previous argument suggested; and to decide whether it will occur or not we adopt the obvious criterion of energy, that is to say, if the strain energy of the slipped crystal is less than that of the unslipped, then slipping will occur. This is illustrated in Fig. 3, where the form *B* will have much less energy than *A*.

The result of this argument is to explain why large metal crystals are so much softer than small, for a shear of one half the atomic distance, measured across the whole width of the crystal, suffices to produce slip, and for a thick crystal this is only a very small shearing strain. There is much else in Bragg's work beyond this which I shall not mention, but we can see how it satisfies the two important conditions, first that it is the crystals themselves that dictate the value of the elastic modulus, and secondly that it is

the reduction in size of the crystals that explains the strength of the metal.

The question then arises whether we can use this theory to reduce the extreme limitation we have derived for the strength of the metal. Evidently the smaller the crystals the stronger the metal should be, but to what limit may we go? For example, if we could think of crystals only two layers thick we should be back at the earlier argument, but such a supposition would signify that nearly all the metal was composed of the irregular arrangements between crystals. An irregular arrangement of atoms of this kind is very like a liquid or a glass, and is very intractable to mathematical treatment, so that it is difficult to say what would happen from the atomic point of view. We may, however, be fairly sure that there would be some tendency to recrystallization, a sort of self-annealing, which would give rise to crystals up to a certain size, because we know that the process of annealing does tend to build up large crystals, and this tells us that the crystalline form has less energy than the glass form.

In this general connexion I would direct attention to the remarkable observations made some years ago by A. A. Griffiths, who found that a thin fibre of glass when newly made had a greatly enhanced strength. The value obtained was quite near that which would be indicated from the shear modulus as in Fig. 2, and this is most interesting as a confirmation of my general argument. With the lapse of time the fibre lost its excessive strength, presumably on account of recrystallization. Until we can know how far a similar recrystallization can be permanently prevented in a metal we cannot further reduce the extreme value we have arrived at for its strength.

As a general conclusion for the extreme limit of strength we may ever hope to attain, I therefore conclude that it is certain we cannot get beyond  $1/2\pi$  of the shear modulus, and that it is most unlikely we can get beyond, say, one tenth of this—which would correspond to having crystals about ten atoms thick and to the rather unwarranted assumption that the irregular junctions would not provide a closer limitation. Since I cannot suggest any exact values for these further effects, I am going to play for safety, and take as the ultimate strength the value  $G/2\pi$ . This is about one hundred times as strong as existing materials.

### Elasticity and Strength

Tension can be much more easily measured and tested than pure shear, and it is often more important in structures, so the engineer tends to think much more about it. I want, however, to raise the question whether tension is not really a secondary thing in the theory of the strength of materials.

The elasticity of an isotropic material has two properties which can be defined in a variety of ways: for example, by giving Young's modulus and the shear modulus, by giving one of them and Poisson's ratio, or by giving one of these three and the bulk modulus, that is, the reaction to hydrostatic stress. From any two of these the rest can be derived, and the only question is which are the best two to take? In other words, which are naturally the most primitive? A rather strong case can be made for taking the bulk modulus and the shear modulus as the two most primitive, since they correspond to the simplest types of strain which can be imposed on a solid body. In effect, this choice is made because it is easier to think of the stress as being called into play by an

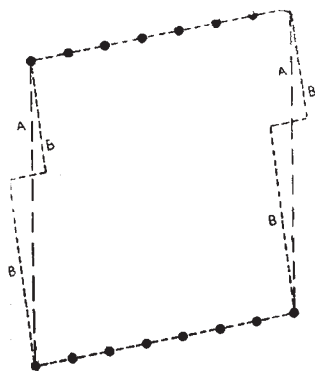


Fig. 3.

assigned strain, than to do what is done in a testing-machine, which is to apply a given stress and see what the strain is. If, then, we are to start with strain as given, there can be no question that a linear tension is a rather complicated thing, involving as it does both a distortion and a change of volume.

This point of view derives from the classical theory of elasticity, and it is a very tentative matter to apply it to the question of ultimate strength. In the first place, some materials break in tension and others in shear, as is easily seen from the shape of the fractured surface. The strongest materials always break in shear, and it seems likely that this is the fundamental manner. I should conjecture that breaking in tension is really a secondary business. If a bar under test contains non-uniformities there will result stress concentrations, and it is the shearing at these concentrations that causes the break. This is only a conjecture, but it leads to the plausible consequence that there is one cause, and not two causes, governing the strength of materials.

Now I have pointed out that the classical theory of elasticity suggests that the bulk modulus is a more primitive thing than is Young's modulus, and this suggests that we should consider what is the 'bulk strength' of materials, that is to say, the manner in which they yield under hydrostatic pressure or tensions. We can immediately answer half this question, for there is no doubt that the metal when hydrostatically compressed resists that compression strongly and shows no tendency to break under it. As to its behaviour under a hydrostatic tension we can scarcely give an answer at all, since it is impossible to apply such a system of forces to a solid. I know of only one experiment where something of the kind has been done. Joffe took a sphere of rock-salt crystal (which is cubic and not far from isotropic) and immersed it in liquid air until it was all of one temperature. He then plunged it in hot oil so that the outer parts expanded, and these parts applied a hydrostatic tension to the inside, which was still cold. The tension showed no tendency to produce cracks.

This one experiment is obviously a rather complex business, but it confirms a tentative conclusion that I wish to draw. The characters of solid matter may be divided into two types, namely, those sensitive to details of structure and those insensitive. All the elastic moduli are fairly insensitive, in that, for example, Young's modulus and the shear modulus are roughly the same for hard and for mild steels; but we know that the shear strength is sensitive. I want to suggest that what evidence there is points to the bulk strength being insensitive to structure. If this is correct, then we have the simplification of theory that we can impute the structure-sensitivity of tensile strength to the shear strength. The advantage of this point of view is that we have only *one* quantity to consider which needs close examination, while the second elastic character plays little part in the consideration of strength.

### Liquids

The two main characters of a liquid are its compressibility and its viscosity. As to compressibility, there is little to be said. At one end we pass over into degrees of resistance to compression comparable with, but not so strong as, those of solids. At the other end we come up against the *critical phenomena* where liquid passes continuously into vapour, so that again there is no extreme property. Viscosity is more

interesting. At one end we have highly viscous materials, such as treacle, then pitch, and then glasses which shade into plastic materials and become indistinguishable from solids. I may also refer to those highly peculiar substances which appear quite stiff but gradually become liquid on stirring, and the converse ones which are liquid, but become stiffer and stiffer as they are stirred; but the theory of these is rather obscure and I must not attempt to discuss them.

At the other end, that of small viscosity, there is much more interest in a particular substance which was discovered only a few years ago. This is liquid helium II. Helium is the substance with the lowest boiling-point of any, about  $4^\circ$  absolute. Liquefaction was achieved in 1908. The next thing to do was to solidify it, but for long no success was achieved, until finally in 1925 it was found that high pressure was essential, and that solid helium could exist only at a pressure of more than 20 atmospheres. But a much more remarkable thing was also found. At ordinary pressures the liquid suddenly changes its character at about  $2^\circ$ . Above this temperature liquid helium I is a fairly ordinary fluid, with a density of about 0.1, and with viscosity and specific heat about the same as those of other liquids. At  $2^\circ$  there is still no change in density or specific heat, but the viscosity drops to a very small value indeed and the heat-conductivity becomes enormous—a hundred times better than that of copper. That, at least, was how the matter appeared at first; but there was a good deal of discrepancy between the measures of various workers, and it was suspected that the viscosity was so low because in every measure turbulence had occurred, while measures of viscosity depend on using such fine tubes that turbulence is eliminated.

Later work has suggested that the matter is not so straightforward, and, in fact, that the character of the substance is not to be explained in terms of the ordinary language used for liquids; but the business is by no means clear yet. We may say, however, that a solid body could move extremely freely in helium II, and that it is practically impossible to keep bodies at different temperatures in its presence: and it has another remarkable characteristic in that the liquid can creep over any surface in apparent defiance of the laws of hydrostatics, so that if a tea-cup were filled with it, in a short time the liquid would appear in the saucer, and then on the table, and finally the level of the liquid would be the same all over whatever space was available.

### Gases

When we come to gases there is little to be said, as the gas laws are very precise and admit of little variation. There are variations of equation of state near the condensation-point, but in the truly gaseous condition the only variety is in the density and the specific heat. The most interesting quantity is the ratio of the specific heats, which governs the law of adiabatic expansion and the speed of sound; this is 5 : 3 for monatomic gases, 7 : 5 for diatomic, and still lower for more complicated molecules. We can say at once that 5 : 3 is the highest ratio that could ever be possible. With regard to density, we can say quite definitely that the limit of lightness is attained by hydrogen.

But if I may extend the meaning of the word 'gas' there are much more interesting things to be said. There does exist matter which is much lighter than hydrogen. This is the electron, which has a mass

1/1840 of that of a hydrogen atom. Electron gas can have only a transient existence, because the enormous repulsive electric forces blow it to pieces at once; but we can take advantage of this transient existence in a more limited way. This is especially in connexion with *relays*, which turn a weak cause into a strong effect. In a quick-acting relay, inertia is obviously of the chief importance in making a given force produce the quickest effect. The force on a body, which in the most delicate systems is almost always electric, depends on the electric charge, while the motion depends on the mass, so that  $e/m$  is a measure of the capability of a system to act as a relay. The  $e/m$  of the electron is 1840 times as large as that of the next best system, the hydrogen atom, and proportionately again better than that of heavier substances. It is this enormous factor that is responsible for the high qualities for amplification of the thermionic valve amplifier.

We know of no reason or evidence that there is anything in the nature of a 'sub-electron', so that we have arrived now at the ultimate limitation in relaying action by the use of the properties of a transiently existing electron gas. It is true that there is something less heavy than electrons, and this is light itself, which carries energy but has no *rest-mass* at all. I have to word this carefully, because in a wider sense anything with energy has mass. But something besides light must always occur in a relay, because at some stage the light has to be acted on or to act on matter with ordinary inertia. The efficiency of a relay is that of its heaviest part, and so we cannot hope by any means to improve on the electronic valve.

Although a free electronic gas can only exist transiently in a tube, there is an extended sense in which it is of much commoner occurrence; this is in the interior of a metal. Here there is a framework of positively charged atoms to neutralize the electron charges, so that the gas can now be permanent. Such a gas has certain properties which are entirely different from those of an ordinary one, a fact which was first recognized with the discovery of the new quantum theory fifteen years ago. The molecules of an ordinary gas are moving about with various and frequently changing velocities, and the frequency of occurrence of these velocities is governed by Maxwell's law of distribution, giving the average numbers at any instant with each velocity in the form of the well-known 'cocked-hat' error law, the size of the curve depending on the absolute temperature.

The electron gas has its velocities distributed quite differently. This is because of the exclusion principle, one of the basic principles of the quantum theory. I must not go into technicalities, but the rule is that two electrons must never be doing the same thing. Thus, if one electron is at rest in the metal no other can be at rest: in an ordinary gas there is no reason why many molecules should not be at rest simultaneously. There are a great many electrons in the metal, and they comply with all the conditions of low energy and many of the higher, so that a lot of them are forced to have quite a high energy. Instead of the Maxwellian figure we get, at ordinary temperatures, a curve with a very sharp fall to zero. The speed at this break corresponds to what in the other curve would be given at a temperature of about 10,000°. To misstate it in picturesque language, the exclusion principle squeezes the electrons out of their rightful temperature; if the metal could be raised to 10,000° without melting, then for the first time the electron gas would behave something like an ordinary gas.

I wish I could enlarge further on this, but it is hard to do so without going more deeply into technicalities. Moreover, my main purpose in mentioning it at all has been because I shall want to return to it in the next subject for discussion.

### Density

We have already considered what is the lightest substance. It is natural next to ask what is the heaviest. Forty years ago there would have been the immediate answer, metallic osmium which has specific gravity 22, and the only saving clause would have been that there might be other unknown elements which would prove heavier. We now know that there are no unknown elements and yet we must answer the question quite differently. This is on account of certain very unexpected astronomical discoveries of about fifteen years ago. Certain stars were discovered which gave out light at a white heat and yet were very faint; they were therefore called white dwarfs. The white heat implied a high temperature, and with this temperature they had no business to be faint; their faintness could only be explained by small size, and this implied a very high density. For example, the companion of Sirius is about the weight of the sun but about the diameter of Uranus, and therefore its mean density must be about 50,000. At this density a cubic inch of the material would weigh about a ton.

The general theory of these dwarfs is understood, though no one knows yet fully why they occur, and what happens to them ultimately. Their structure is an extreme case of the electron gas in a metal. In the interior of a star the temperature is so enormous—millions of degrees—that the atoms lose most of their electrons, and this large number of electrons becomes subject to the exclusion principle. According to this principle there is a simple relation between pressure and density which is independent of temperature; it is the same relation as that which applies for the adiabatic expansion of a monatomic gas. So long as the temperature is not too high (and by high temperature I now mean something like a hundred million degrees) this relation holds and implies that under sufficiently high pressures there is no limit to the density. As in most things of this kind, the result must not be pushed too far, because we have omitted certain secondary matters which ultimately become important. But there is good reason to believe that in the deep interior of white dwarfs there are densities of something like two tons to the cubic inch—specific gravity a hundred thousand—which are maintained by pressures of the order of a million million atmospheres. It seems reasonable to hope that this is a final limitation on the density of matter.

### Electrical Properties of Matter

What is the best insulator we can hope for? Here the answer is fairly definite; we already have it in the form of good transparent crystals such as quartz. The theory of insulators, as formulated nowadays, is curiously like that of conductors. The individual electrons in both are free to move about in the crystal, but the exclusion principle leads to an important difference. In the case of metals there is, so to speak, room for an electron to behave in a different way from what it is doing—not all the seats are occupied—so that it can wander about carrying its electricity with it. In an insulator there is a full

house, so that when one electron shifts its place another is forced at once to take that place, and there can be no transport of electricity, and so no conduction.

There are two ways in which insulators fail. First, the surface often becomes covered with some foreign material, often merely water, which causes a leak over it. The second failure is much more interesting. One way of escaping from the rigour of the exclusion principle is to provide an electron with a good deal of energy, because then it can be 'doing something different' from the others. If a crystal, say of rock salt, is illuminated with ultra-violet light, some of its electrons absorb the light and acquire a high energy which sets them free to wander through the crystal. In this way a conductivity not unlike that of electrolysis arises. To get a perfect insulator this must be avoided, and it can best be done by keeping the crystal in the dark and, since there is always radiation due to temperature, to make it very cold will also help.

At the other end of the scale, what is the best electrical conductor? Here also we can make a rather definite answer. The conductivity of alloys is worse than that of their constituent elements, both theoretically and in practical experience, so that we need only examine the table of the elements to see which is best. If we reckon by weight this is sodium, but others are nearly as good. But a far more important question is the temperature. The conductivity improves with cold, and tends to very high values at the absolute zero. It is not certain whether it might not become infinite, but as a general rule there seems to be a small residual resistance.

The interest of this is very much diminished by the extraordinary phenomenon of superconductivity. Certain of the elements—not by any means the best conductors at room temperature—and also some alloys and compounds, as the temperature drops, suddenly become perfect conductors; lead does so at 4° K., so that if a current is started in a lead ring below this temperature it just goes on for ever—always provided the stock of cooling liquid lasts. This is a fascinating subject of study, not by any means cleared up yet, which possesses many of the characters of the older physics of Faraday rather than of modern atomic physics. There are, however, pronounced limitations in its practical utility because superconductivity is sensitive to magnetic fields, and fails when the field is strong, so that if too great a current is carried by a superconducting wire, that current's own field destroys the superconductivity.

### Magnetism

The question of magnetism is also interesting because such great technical advances have been made in it lately. I can only touch on some parts of the subject, in particular on permeability and saturation values. Of these, the permeability at low fields is important for many purposes. The value for mumetal is about 60,000, and we may ask whether this could be increased.

According to present ideas, iron and nickel have the property of being spontaneously magnetized in small domains, and all that the external field does at first is to turn the direction of spontaneous magnetization into another direction of easy magnetization. There does not seem any particular limitation on this process, so that we can see no reason why quite a small field should not give practical saturation.

Thus we know no reason why there should not be a better mumetal in the sense that the permeability for weak fields might be much larger; but correspondingly the exciting field would have to be reduced, or saturation would ensue.

The question of magnetic saturation may be answered much more definitely, since there exists a fairly complete atomic theory. We can say that it is certain that nothing can show magnetic saturation much greater than that of iron, and it is extremely unlikely that anything will be found perceptibly better than iron. In this matter of saturation we are not concerned with the ease or difficulty with which the magnetization can be set up. In iron it is spontaneous, whereas in some substances it calls for such strong external fields that nothing like the maximum has ever been attained. There is a natural unit of magnetization, the Bohr magneton, but theory indicates that there is no reason why an atom should possess an exact whole number of magnetons. Thus iron has 2.2, cobalt 1.7, and nickel 0.6. The largest number known is in the rare earth europium, some salts of which have 10. This is in exact accord with theory, and as the theory has been applied to the whole table of elements, we can confidently say that it is no use expecting anything better. This magnetization is in the salt, where the europium atoms are fairly far separated from one another, so that the total magnetization is not very large. The europium atom is three times as heavy as the iron atom, so that even if the full magnetization could be produced in the metal, the resulting value would only be half as much again as it is for iron. That is why I said that there was very little expectation of getting anything better than iron.

### Summary

I have ranged over a wide field of properties of matter, and had better summarize them in conclusion. I am going to do so in a fanciful manner by taking a structure built out of all the extreme materials I have imagined and seeing what it is like.

I propose to rebuild the ship *Queen Elizabeth*. My metal is one hundred times as strong as that used in the present ship. I do not propose to go into complicated questions of design; for example, the tension members can be immediately lightened one hundred times, but the thrust members will have to be much enlarged tubes in order to remain stable. I see no reason why I should not build the ship with one-hundredth of the weight of material. As the ironwork weighs something like 30,000 tons in the present ship, my ship will weigh only 300 tons. Therefore, to get the displacement, I shall have to ballast it with nearly 30,000 tons before I begin to put in the cargo. I immediately think of using material from a 'white dwarf' star for this, and my ballast will then occupy about 17 cubic feet. However, I now notice that there will be technical difficulties in this way of doing things, since I should have to keep it at a pressure of one billion atmospheres and at a temperature of one hundred million degrees, so I give up this idea and fall back on ballast made of metallic osmium, of which I shall require as much as 50,000 cubic feet, say a block in the form of a cube of 12 yards side. It is time now to attend to the machinery. Presumably I shall think of putting in an atomic engine, but the trouble is that whatever the engine itself may be like, so far as I can see it will have ultimately to raise steam for a turbine, so that my

engine-room will still have to be quite large. For the auxiliary machinery I will certainly take advantage of superconductivity, so that the wiring of the ship will be cooled by liquid helium; it must be made of tin or lead wire, since copper is not a superconductor. The magnets in the dynamos will scarcely be different from those already in use.

This suggests a further flight of fancy. My ship on its journeys still has to contend with the resistance of the water. Would it not be more economical to alter the composition of the sea into something less resistant? If it is liquid helium II, I can economize in many ways. I shall need no special cooling for the superconducting electric wires. I can leave out nine tenths of the ballast, since the density of the sea is now reduced to one tenth. It is possible that I can give up having an engine altogether by giving the ship a good shove at the start of the journey and receiving it on buffers at the end; I know too little about the real viscosity to judge of this.

But the end of all my plans is tragedy. On account of another of its properties the liquid helium II will irresistibly creep up the sides of the ship, over the bulwarks, across the deck, and down the companion ways, until it settles in the hold, in the effort to come to the same level inside as out. Deeper and deeper will grow the water in the hold, and deeper and deeper the ship will settle, until at last my imaginary ship will founder in the depths of the imaginary ocean.

## RESEARCH IN THE NETHERLANDS INDIES\*

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**R**ESearch in the Netherlands Indies which tried to improve existing or developing processes was, and is, principally concerned with agriculture in all its aspects. Research in the field of mining had to do with the geological surveys of mechanical engineering as well as metallurgical and civil engineering.

Most of the progress in the Indies has been culled from experience gained in Europe; new scientific aid from Japan, other countries and even from the United States has been of limited significance, except, perhaps, in military matters.

It is not the purpose of this article to discuss medical research, although in the past fifteen years the relation between nutrition, hygiene and the health of the population has been intensified.

Research, as it has been organized in the Netherlands Indies, has to do, primarily, with agriculture and technology. Agriculture includes agronomy, diseases (phytopathology and entomology) and the methods of planting, selection of varieties, application of fertilizers; the study of technology is directed towards improving the methods of manufacture of agricultural products.

The beginning of research work in the Netherlands Indies is seen as far back as the origin of the Botanical Gardens in Buitenzorg some sixty years ago. Without doing injustice to its former directors Teismann and Blume, or to individual explorers such as Rumphius and Junghuhn, the real beginning of systematic

research began about 1880. Before that time, however, there was a separate survey of the natural wealth of the Netherlands Indies, with the idea of having a detailed summary on minerals, fauna and flora, the geological formations, and the character of natural conditions regarding temperature and weather.

The principle of using science and scientific men to improve existing agricultural industries was first developed in Europe, and it is certain that Germany played a leading part during 1870-1890 in this matter. Treub, of the same era, was ideal as director of the Botanical Gardens. He worked on the plan of introducing science for practical application, although it was his original contention that most of the scientific research, for application to special plantation crops, must be affiliated with Buitenzorg. He believed this necessary in order to centralize in one way or another the scientific work; he thought it to be advantageous to move scientific workers about. The idea of centralization was not used, however, by the new "Proef-stations", as the first research centres were called.

The first research centres were organized as private institutions. There were stations for sugar, tobacco, coffee, indigo and for forestry in general. Later, there followed similar centres for tea, rubber, cinchona, palm oil. Then came the Government Agricultural Institute for the study of native crops: rice, copra, cassava, soja, maize and similar produce. The research organizations previous to 1900 employed, in general, phytopathologists; but later agriculturists and biologists, specializing in genetics and physiology, were introduced. In 1930, for example, the total number of workers on the staffs of the Netherlands Indies Governmental and private institutes was 190. These included those working in the fields of agriculture, agricultural industries and technology. All of them were graduates and experts.

At the start, the selection of the research workers was on a broad international base, and most of the European countries sent men of science to work in the Netherlands Indies. This international co-operation was of great benefit to the country. Further, there were the universities in Holland where it was possible to give a limited number of students thorough training. The Netherlands Indies also had the good fortune to have men of science who could read three major foreign languages.

The total number of experts who worked in the Netherlands Indies from 1880 until 1935 was about 850. About 250 of these men had been connected with the Experimental Station for the sugar industry. More than one quarter were foreign residents, while the average time these men were connected with research in the tropics was seven to eight years.

The total number of chemists, agriculturists and biologists engaged in the Netherlands Indies was much greater, however, than the above-mentioned figures. In 1939, there were 250 chemists, of whom 50 were doing research; the others dealt with education, manufacturing processes, consulting agencies and the like. Of the agriculturists, research workers numbered 45 out of 700 in 1939. There were 90 biologists with 25 research workers. The geologists numbered 70, of whom seven were engaged in research. The number of pharmacists was 200, eight of whom were research workers.

Until 1939, the number of Indonesians and Chinese working in science was very small, and the indigenous part of the population provided only five research

\* Substance of an address given at the September meeting of the Society of Netherlands Scientists in the U.S.A. at Cornell University.