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VISION IN NATURE AND VISION AIDED BY SCIENCE; SCIENCE AND WARFARE[1]

By The Rt. Hon. LORD RAYLEIGH
PRESIDENT OF THE ASSOCIATION

I. VISION, AND ITS ARTIFICIAL AIDS AND SUBSTITUTES

THE last occasion that the British Association met at Cambridge was in 1904, under the presidency of my revered relative, Lord Balfour, who at the time actually held the position of Prime Minister. That a Prime Minister should find it possible to undertake this additional burden brings home to us how much the pace has quickened in national activities, and I may add, anxieties, between that time and this.

Lord Balfour in his introductory remarks recalled the large share which Cambridge had had in the development of physics from the time of Newton down to that of J. J. Thomson and the scientific school centered in the Cavendish Laboratory, "whose physical speculations," he said, "bid fair to render the closing year of the old century and the opening ones of the new as notable as the greatest which have preceded them." It is a great pleasure to me, as I am sure it is to all of you, that my old master is with us here to-night, as he was on that occasion. I can say in his presence that the lapse of time has not failed to justify Lord Balfour's words. What was then an intelligent anticipation is now a historical fact.

I wish I could proceed on an equally cheerful note. The reputation of the scientific school in the Cavendish Laboratory has been more than sustained in the interval under the leadership of one whose friendly pres-

[1] Address of the President of the British Association for the Advancement of Science, Cambridge, August, 1938.

ence we all miss to-night. The death of Ernest Rutherford leaves a blank which we can never hope to see entirely filled in our day. We know that the whole scientific world joins with us in mourning his loss.

Lord Balfour's address was devoted to topics which had long been of profound interest to him. He was one of the first to compare the world picture drawn by science and the world picture drawn by the crude application of the senses, and he emphasized the contrast between them. A quotation from his address will serve as an appropriate text to introduce the point of view which I wish to develop this evening.

"So far," he said, "as natural science can tell us, every quality or sense or intellect which does not help us to fight, to eat and to bring up our children, is but a by-product of the qualities which do. Our organs of sense perception were not given us for purposes of research . . . either because too direct a vision of physical reality was a hindrance, not a help in the struggle for existence . . . or because with so imperfect a material as living tissue no better result could be attained."

Some of those who learn the results of modern science from a standpoint of general or philosophical interest come away, I believe, with the impression that what the senses tell us about the external world is shown to be altogether misleading. They learn, for example, that the apparent or space-filling quality of the objects called solid or liquid is a delusion and that the volume of space occupied is held to be very small compared with that which remains vacant in between. This is in such violent contrast with what direct observation seems to show that they believe they are asked to give up the general position that what we learn from our senses must be our main guide in studying the nature of things.

Now this is in complete contrast with the standpoint of the experimental philosopher. He knows very well that in his work he does and must trust in the last resort almost entirely to what can be seen and that his knowledge of the external world is based upon it; and I do not think that even the metaphysician claims that we can learn much in any other way. It is true that the conclusions of modern science seem at first sight to be very far removed from what our senses tell us. But on the whole the tendency of progress is to bring the more remote conclusions within the province of direct observation, even when at first sight they appeared to be hopelessly beyond it.

For example, at the time of Lord Balfour's address some who were regarded as leaders of scientific thought still urged that the conception of atoms was not to be taken literally. We now count the atoms by direct methods. We see the electrometer needle give a kick and we say, "There goes an atom." Or we see the path of an individual atom marked out by a cloud track and we see where it was abruptly bent by a violent collision with another atom.

Again, the theory of radioactive decomposition put forward by Rutherford, however cogent it may have seemed and did seem to those who were well acquainted with the evidence, was originally based on indirect inferences about quantities of matter far too small to be weighed on the most delicate balance. Chemists were naturally inclined to feel some reserve; but in due course the theory led to a conclusion which could be tested by methods in which they had confidence—the conclusion, namely, that lead contained in old uranium minerals ought to have a lower atomic weight than ordinary lead and in all probability to be lighter, and on trying this out it proved to be so. More recently we have the discovery of heavy hydrogen with twice the density of ordinary hydrogen and heavy water which is the source of it.

Lastly, the conclusion that ordinary matter is not really space-filling has been illustrated by the discovery that certain stars have a density which is a fabulous multiple of the density of terrestrial matter. Although this is in some sense a deduction as distinguished from an observation, yet the steps required in the deduction are elementary ones entirely within the domain of the older physics.

This and many other points of view have seemed at first sight to contradict the direct indication of our senses. But it was not really so. They were obtained and could only be obtained by sense indications rightly interpreted. As in the passage from Lord Balfour already quoted the senses were not primarily developed for purposes of research, and we have in large measure to adapt them to that purpose by the use of artificial auxiliaries. The result of doing so is often to reveal a world which to the unaided senses seems paradoxical.

I have chosen for the main subject of this address a survey of some of the ways in which such adaptations have been made. I shall naturally try to interest you by dwelling most on aspects of the subject that have some novelty; but apart from these there is much to be gleaned of historical interest, and when tempted I shall not hesitate to digress a little from methods and say something about results.

I shall begin with a glance at the mechanism of the human eye, so far as it is understood. I shall show how the compromise and balance between different competing considerations which is seen in its design can be artificially modified for special purposes. All engineering designs are a matter of compromise. You can not have everything. The unassisted eye has a field of view extending nearly over a hemisphere. It gives an indication very quickly and allows comparatively rapid changes to be followed. It responds best to the wave-lengths actually most abundant in daylight or moonlight. This combination of qualities is ideal for what we believe to be nature's primary purpose, that is for finding subsistence under primitive conditions and for fighting the battle of life against natural enemies. But by sacrificing some of these qualities, and in particular the large field of view, we can enhance others for purposes of research. We may modify the lens system by artificial additions over a wide range for examining the very distant or the very small. We can supplement and enormously enhance the power of color discrimination which nature has given us. By abandoning the use of the retina and substituting the photographic plate as an artificial retina, we can increase very largely the range of spectrum which can be utilized. This last extension has its special possibilities, particularly in the direction of using waves smaller than ordinary, even down to those which are associated with a moving electron. By using the photoelectric cell as another substitute for the retina with electric wire instead of optic nerve and a recording galvanometer instead of the brain we can make the impressions metrical and can record them on paper. We can count photons and other particulate forms of energy as well. We can explore the structure of atoms, examine the disintegration of radioactive bodies, and trace out the mutual relation of the elements. Indeed, by elaborating this train of thought a little further almost the whole range of observational science could be covered. But within the compass of an hour or so one must not be too ambitious. It is not my purpose to stray very far from what might, by a slight stretch of language, fall under the heading of extending the powers of the eye.

Most people who have a smattering of science now know the comparison of the eye with the camera obscura, or better, with the modern photographic camera—with its lens, iris, diaphragm, focussing adjustment and ground glass screen, the latter corresponding to the retina. The comparison does not go very far, for it does not enter upon how the message is conveyed to the brain and apprehended by the mind; or even upon the minor mystery of how colors are discriminated. Nevertheless, it would be a great mistake to suppose that the knowledge which is embodied in this comparison was easily arrived at. For example, many acute minds in antiquity thought that light originated in the eye rather than in the object viewed. Euclid in his optics perhaps used this as a mathematical fiction practically equivalent to the modern one of reversing the course of a ray, but other authors appealed to the apparent glow of animal eyes by lamplight, which shows that they took the theory quite literally. The Arabian author Alhazen had more correct ideas and he gave an anatomical description of the eye, but apparently regarded what we call the crystalline lens as the light-sensitive organ. Kepler was the first to take the modern view of the eye.

The detailed structure of the retina, and its connection with the optic nerve, has required the highest skill of histologists in interpreting difficult and uncertain indications. The light-sensitive elements are of two kinds, the rods and cones. The rods seem to be the only ones used in night vision, and do not distinguish colors. The cones are most important in the center of the field of view, where vision is most acute, and it seems to be fairly certain that in the foveal region each cone has its own individual nervous communication with the brain. On the other hand, there is not anything like room in the cross-section of the optic nerve to allow us to assign a different nerve fiber to each of the millions of rods. A single fiber probably has to serve 200 of them.

The nervous impulse is believed to travel in the optic nerve as in any other nerve, but what happens to it when it arrives at the brain is a question for the investigators of a future generation.

The use of lenses is one of the greatest scientific discoveries: we do not know who made it. Indeed, the more closely we inquire into this question the vaguer it becomes. Spectacle lenses as we know them are a medieval invention, dating from about A.D. 1280. Whether they originated from some isolated thinker and experimentalist of the type of Roger Bacon, or whether they were developed by the ingenuity of urban craftsmen, can hardly be considered certain. There are several ways in which the suggestion might have arisen, but a glass bulb filled with water is the most likely. Indeed, considering that such bulbs were undoubtedly used as burning glasses in the ancient world, and that the use of them for reading small and difficult lettering is explicitly mentioned by Seneca, it seems rather strange that the next step was not taken in antiquity. Apparently the explanation is that the magnification was attributed to the nature of the water rather than to its shape. At all events, it may readily be verified that a 4- or 5-inch glass flask full of water, though not very convenient to handle, will give a long-sighted newspaper reader the same help that he could get from a monocle.

The invention of lenses was a necessary preliminary to the invention of the telescope, for, as Huygens remarked, it would require a superhuman genius to make the invention theoretically.

The retina of the eye on which the image is to be received has structure. We may compare the picture on the retina to a design embroidered in woolwork, which also has a structure. Clearly such a design can not embody details which are smaller than the mesh of the canvas which is to carry the colored stitches. The only way to get in more detail is to make the design, or rather such diminished part of it as the canvas can accommodate, on a larger scale. Similarly with the picture on the retina. The individual rods and cones correspond with the individual meshes of the canvas. If we want more detail of an object we must make the picture on the retina larger, with the necessary sacrifice of the field of view. If the object is distant we want for this a lens of longer focus instead of the eye lens. We can not take the eye lens away, but, what amounts to nearly the same thing, we can neutralize it by a concave lens of equal power put right up to it, called the eyepiece. Then we are free to use a long focus lens called the telescopic objective to make a larger picture on the retina. It must of course be put at the proper distance out to make a distinct picture. This is a special case of the Galilean telescope, which lends itself to simple description. It is of no use to make the picture larger if we lose definition in the process. The enlarged image must remain sharp enough to take advantage of the fine structure of the retinal screen that is to receive it. It will not be sharp enough unless we make the lens of greater diameter than the eye. Another reason for using a large lens is to avoid a loss of brightness.

It seems paradoxical that the image of a star should be smaller the larger the telescope. Nevertheless it is a necessary result of the wave character of light. We can not see the true nature of, for example, a double star unless the two images are small enough not to overlap and far enough apart to fall on separated elements of the observer's retina.

When the problem is to examine small objects we look at them as close as we can: here the short-sighted observer has an advantage. By adding a lens in front of the eye lens to increase its power we can produce a kind of artificial short sight and get closer than we could otherwise, so that the picture on the retina is bigger. This is a simple microscope and we can use it to examine the image produced by an objective lens; if this image is larger than the object under examination we call the whole arrangement a compound microscope.

Given perfect construction there is no limit in theory to what a telescope can do in revealing distant worlds. It is only a question of making it large enough. On the other hand, there is a very definite limit to what the microscope used with, say, ordinary daylight can do. It is not that there is any difficulty in making it magnify as much as we like. This can be done, *e.g.*, by making the tube of the microscope longer. The trouble is that beyond a certain point magnification does no good. Many people find this a hard saying, but it must remembered that a large image is not necessarily a good image. We are up against the same difficulty as before. A point on the object is necessarily spread out into a disc in the image, due to the coarseness of structure of light itself as indicated by its wave-length. I can not go into the details, but many of you will know that points on the object which are something less than half a wave-length, or say a one-hundred-thousandth of an inch apart, can not be distinctly separated. This is the theoretical limit for a microscope using ordinary light, and it has been practically reached. The early microscopists would have thought this more than satisfactory; but the limit puts a serious obstacle in the way of biological and medical progress to-day. For example, the pathogenic bacteria in many cases are about this size or less; and there is special interest in considering in what directions we may hope to go further.

Since microscopic resolution depends on having a fine structure in the light itself, something, though not perhaps very much, may be gained by the use of ultra-violet light instead of visible light. It then becomes necessary to work by photography. We are nearing the region of the spectrum where almost everything is opaque. In the visual region nearly every organic structure is transparent and to get contrast stains have to be used which color one part more deeply than the other. In the ultra-violet, on the other hand, we get contrast without staining and, as Mr. J. W. Barnard has shown, the advantage lies as much in this as in the increased resolving power. For example, using the strong ultra-violet line of the mercury vapor lamp, which has about half the wave-length of green light, he finds that a virus contained within a cell shows up as a highly absorptive body in contrast with the less absorptive elements of the cell. So that ultra-violet microscopy offers some hope of progress in connection with this fundamental problem of the nature of viruses.

With ultra-violet microscopy we have gone as far as we can in using short waves with ordinary lenses made of matter, for the available kinds of matter are useless for shorter waves than these, and it might well seem that we have here come to a definite and final end. Yet it is not so. There are two alternatives, which we must consider separately. Paradoxical as it may seem, for certain radiations we can make converging lenses out of empty space; or alternatively we can make optical observations without any lenses at all.

The long-standing controversy which raged in the nineties of the last century as to whether cathode rays consisted of waves or of electrified particles was thought to have been settled in favor of the latter alternative. But scientific controversies, however acutely they may rage for a time, are apt, like industrial disputes, to end in compromise; and it has been so in this instance. According to our present views the cathode rays in one aspect consist of a stream of electrified particles; in another, they consist of wave trains, the length being variable in inverse relation to the momentum of the particles.

Now cathode rays have the property of being bent by electric or magnetic forces, and far-reaching analogies have been traced between this bending and the refraction of light by solids; indeed, a system of "electron optics" has been elaborated which shows how a beam of cathode rays issuing from a point can be reassembled into an image by passing through a localized electrostatic or magnetic field having axial symmetry. This constitutes what has been called an electrostatic or magnetic lens. It is then possible to form a magnified image of the source of electrons on a fluorescent screen, and that is the simplest application. But we can go further and form an image of an obstructing object such as a fine wire by means of one magnetic lens, acting as objective, and amplify it by means of a second magnetic lens, which is spoken of as the eyepiece, though of course it is only such by analogy, for the eye can not deal directly with cathode rays. The eyepiece projects the image on to a fluorescent screen or photographic plate. So far we have been thinking of the electron stream in its corpuscular aspect. But we must turn to the wave aspect when it comes to consideration of theoretical resolving power. The wavelength associated with an electron stream of moderate velocity is so small that if the electron microscope could be brought to the perfection of the optical microscope, it should be able to resolve the actual atomic structure of crystals. This is very far indeed from being attained, the present electron microscope being much further from its own ideal than were the earliest optical microscopes. Nevertheless, experimental instruments have been constructed which have a resolving power several times better than the modern optical microscope. The difficulty is to apply them to practical biological problems.

It is not to be supposed that the histological technique so skilfully elaborated for ordinary microscopy can at once be transferred to the electron microscope. For example, the relatively thick glass supports and covers ordinarily used are out of the question. Staining with aniline dyes is probably of little use, and the fierce bombardment to which the delicate specimen is necessarily exposed will be no small obstacle. Certain standard methods, however, such as impregnation with osmium, seem to be applicable: and there is some possibility that eventually the obscure region between the smallest organisms and the largest crystalline structure may be explored by electron microscopy.

In referring to the limitations on the use of lenses I mentioned the other alternative that we might, in order to work with the shortest waves, dispense with lenses altogether: and in fact in using x-rays this is done. We are then limited to controlling the course of the rays by means of tubes or pinholes. This restriction is so serious that it altogether defeats the possibility of constructing a useful x-ray microscope analogous to the optical or the electron microscope. In spite of this the use of x-rays is of fundamental value for dealing with a particular class of objects, namely, crystals, which themselves have a regular spacing, comparable in size with the length of the waves. Just as the spacing of a ruled grating (say one 1/20,000th of an inch) can be compared with the wave-length of light by measuring the angle of diffraction, so the spacing of atoms in a crystal can be compared with the wave-length of x-rays. But here the indications are less direct than with the microscope, and depend on the object having a periodic structure. So that the method hardly falls within the scope of this address. How essential the difference is will appear if we consider that the angle to be observed becomes greater and not less the closer the spacing of the object under test.

Color vision is one of nature's most wonderful achievements, though custom often prevents our perceiving the wonder of it. We take it for granted that any one should readily distinguish the berries on a holly bush, and we are inclined to be derisive of a color-blind person who can not do so. But so far anatomy has told us little or nothing of how the marvel is achieved. Experiments on color vision show that three separate and fundamental color sensations exist. It is probable that the cones of the retina are responsible for color vision and the rods for dark adapted vision which does not discriminate color. But no division of the cones into three separate kinds corresponding to the three color sensations has ever been observed. Nor is any anatomical peculiarity known which allows a color-blind eyes to be distinguished from a normal one.

Can artificial resources help to improve color discrimination? In some interesting cases they can. Indeed, the whole subject of spectroscopy may be thought of as coming under this head. We can recognize the color imparted by sodium to a flame without artificial help. When potassium is present as well, the red color due to it can only be seen when we use a prism to separate the red image of the flame from the yellow one. Such a method has its limitations, because if the colored images are more numerous they overlap, and the desired separation is lost. To avoid this it is necessary to make a sacrifice, and to limit the effective breadth of the flame by a more or less narrow slit. And if the images are very numerous the slit has to be so narrow that all indication of the breadth of the source is lost. This, of course, is substantially the method of spectroscopy, into which I do not enter further. But there is an interesting class of cases where we can not afford to sacrifice the form of the object entirely to color discrimination. Consider, for example, the prominences of the sun's limb, which are so well seen against the darkened sky of an eclipse, but are altogether lost in the glare of the sky at other times. In order to see them prismatic dispersion is made use of, and separates the monochromatic red light of hydrogen from the sky background. A slit must be used to cut off the latter: but if it is too narrow the outlines of the prominence can not be seen. By using a compromise width it is possible to reconcile the competing requirements in this comparatively easy case. Indeed, M. B. Lyot, working in the clear air of the observatory of the Pic du Midi, where there is less false light to deal with, has even been able to observe the prominences through a suitable red filter, which enables the whole circumference of the sun to be examined at once, without the limitations introduced by a slit. A much more difficult problem is to look for bright hydrogen eruptions projected on the sun's disc, and at first sight this might well seem hopeless. A complete view of them was first obtained by photography, but I shall limit myself to some notice of the visual instrument perfected by Hale and called by him the spectrohelioscope. A very narrow slit has to be used, and hence only a very small breadth of the sun's surface can be seen at any one instant. But the difficulty is turned by very rapidly exposing to view successive strips of the sun's surface side by side. The images then blend, owing to persistence of vision, and a reasonably broad region is included in what is practically a single view. I must pass over the details of mechanism by which this is carried out.

There are now a number of spectroheliosopes over different parts of the world, and a continuous watch is kept for bright eruptions of the red hydrogen lines. Already these are found to be simultaneous with the "fading" of short radio waves over the illuminated hemisphere of the earth, and the brightest eruptions are simultaneous with disturbances of terrestrial magnetism. At the Mount Wilson Observatory such eruptions have been seen at the same time at widely separated points on the sun, indicating a deep-seated cause. There are therefore very interesting and fundamental questions within the realm of this method of investigation.

We have so far been mainly considering how we may adapt our vision for objects too small or too far off for unassisted sight, and for color differences not ordinarily perceptible. This is chiefly done by supplementing the lens system of the eye by additional lenses or by prisms. We can not supplement the retina, but in certain cases we can do better. We can substitute an artificial sensitive surface which may be either photographic or photoelectric.

That certain pigments are bleached by light is an observation that must have obtruded itself from very early time—indeed, it is one of the chief practical problems of dyeing to select pigments which do not fade rapidly. If a part of the colored surface is protected by an opaque object—say a picture or a mirror hanging over a colored wallpaper—we get a silhouette of the protecting object, which is in essence a photograph.

Again, it is a matter of common observation that the human skin is darkened by the prolonged action of the sun's light, and here similarly we may get what is really a silhouette photograph of a locket, or the like, which protects the skin locally. In this case we are perhaps retracing the paths which nature herself has taken: for the evolution of the eye is regarded as having begun with the general sensitiveness to light of the whole surface of the organism.

The sensitivity of at all events the dark adapted eye depends on the accumulation on the retinal rods of the pigment called the visual purple, of which the most striking characteristic is its ready bleaching by light. We can even partially "fix" the picture produced in this way on the retina of, for example, a frog by means of alum solution. This brings home to us how clearly akin are the processes in the retina to those in the photographic plate, even though the complexity of the former has hitherto largely baffled investigation.

There are then many indications in nature of substances sensitive to light, and quite a considerable variety of them have from time to time been used in practical photographic processes. But compounds of silver, which formed the basis of the earliest processes, have maintained the lead over all others. The history of photography by means of silver salts can not be considered a good example of the triumph of the rational over the empirical. For instance, the discovery of developers came about thus. The first workers, Wedgewood and Davy (1802), had found that they got greater sensitivity by spreading the silver salt on white leather instead of paper. An early experimenter, the Reverend J. B. Reade (1837), was anxious to repeat this experiment, and sacrificed a pair of white kid gloves belonging to his wife for the purpose. When he wished to sacrifice a second pair, the lady raised a not unnatural objection, and he said, 'Then I will tan paper.' He treated paper with an infusion of oak galls and found that this increased the sensitivity greatly. It amounted to what we should call exposing and developing simultaneously. But, in using the method, it is easily observed that darkening continues after exposure is over, and this leads to beginning development after the exposure. This step was taken by Fox Talbot a year or two afterwards. Instead of crude infusion of galls he used gallic acid. Later pyrogallic acid was used instead of gallic acid, and still survives.

The use of gelatine as a medium to contain the silver halide was a more obvious idea. But it was not so easy to foresee that the sensitivity of silver salts would be much further increased when they were held in this medium. For long this remained unexplained, until it was noticed that some specimens of gelatine were much more active than others. This was ultimately traced by S. E. Sheppard to the presence of traces of mustard oil, a sulfur compound, in the more active specimens. This, in turn, depends in all probability on the pasturage on which the animals that afford the gelatine have been fed. The quantity present is incredibly small, comparable in quantity with the radium in pitchblende.

(To be concluded)

SCIENTIFIC EVENTS

AGRICULTURAL RESEARCH AT ROTHAMSTED

LORD FEVERSHAM, parliamentary secretary to the British Minister of Agriculture, announced recently that the Rothamsted Experimental Station at Harpenden, the oldest agricultural research institution in the world, had been granted £14,500 by the British government to meet half the cost of building extensions. The station hopes to celebrate its centenary in 1943 with a comprehensive building scheme.

According to the London *Times,* the investigations in progress at the experimental field plots and laboratories include research into the "take-all" infective disease, found in all places where there is an alkali light soil, which attacks wheat. In other parts of the world it is a serious disease, and Australia can lose 80 to 90 per cent. of a crop. With the development of mechanized farming the disease has appeared in Great Britain. The fungus persists in the soil, but it has been found that ground rye meal will halve its persistence.

The Department of Entomology is studying the migration of insects and their relation to climatic conditions. Ingenious traps have been arranged, some like glass lobster pots, which have been out in the fields for four years. The catch one night was 70,000 insects. With the data collected the station can get a measure of the total abundance of insects and so issue forecasts. Some of the experimental field plots have been under surveillance for 100 years.

At a luncheon given by the Lawes Agricultural Trust Committee, Lord Radnor, who presided, referred to the importance of Rothamsted. Since 1919 the loss of agricultural land was very nearly 20,000,000 acres, and while only 20 per cent. of this was due to town expansion, there was a considerable area of rough grazing and unproductive land. Many countries, on which Great Britain relied, were finding that the stored fertility of the land was coming to an end and that they would have to find other methods of agricultural production to maintain fertility.

RESEARCH LABORATORIES AUTHORIZED BY THE AGRICULTURAL ADJUSTMENT ACT

SECRETARY WALLACE has announced that research laboratories authorized by the Agricultural Adjustment Act of 1938 will be established in four major farm-producing areas. He also named the surplus farm commodities on which the work will be done during the initial program. Section 202 of the Agricultural Adjustment Act of 1938 instructs the Secretary of Agriculture to establish four regional research laboratories for research on new uses and market outlets for agricultural products. According to the law, funds available for the laboratories and their work must be divided equally among the four.

The areas are to be known as the Southern, Eastern, Northern and Western major farm producing areas. The states included in these areas are:

Southern Area: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Oklahoma, South Carolina and Texas.

Eastern Area: Connecticut, Delaware, Kentucky, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, Tennessee, Vermont, Virginia and West Virginia.

Northern Area: Illinois, Indiana, Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin and Michigan.

Western Area: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington and Wyoming.

In deciding on this grouping of states the distribution and type of agriculture production, farm population, farm income, value of farm property, total population and other facts were taken into account. Secretary Wallace pointed out that it is of first importance that the research load among the four laboratories should be equalized and coordinated for the efficient performance of the task specified by the Congress. This is especially necessary because the total funds available for these laboratories, $4,000,000, must be equally divided among them. He stated that the department had given full consideration to questions bearing on regional interest and unity in each area. They had realized from the beginning that the four major farm producing areas must be so defined and the work so organized that it would be possible ultimately to include in the program, so far as resources permitted, the major surplus commodities of interest to any area. The central idea throughout had been to secure results efficiently. These results