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INFRA-RED SPECTROSCOPY[1]

SIR WILLIAM HERSCHEL is generally credited with having first demonstrated the presence of an infra-red spectrum. His experimental procedure, as reported under the date of April 24, 1800, in the Philosophical Transactions of the Royal Society, was simple and effective. A prism resolved a beam of sunlight passing through a slit in a shutter into a spectrum which fell upon a table. By placing in the region beyond the red end of the spectrum the blackened bulb of a thermometer, he found that it registered a rise in temperature: an even greater rise in temperature than occurred when the bulb was inserted in the red band of the spectrum. As the bulb was moved outward from the red end of the spectrum, this effect was found to reach a maximum and then to diminish rapidly to zero. Since the thermometer also registered a rise in temperature when placed in any one of the seven colored bands into which Newton had divided the spectrum, the question arose as to whether the visible spectrum consisted of a single radiation which produced both illumination and heat, when received upon solid surfaces, or of two distinct agencies, one resulting in illumination and one in heat effects. His statement of the problem is so admirable that I quote it in its entirety:

> . . . if we call light, those rays which illuminate objects, and radiant heat, those which heat bodies, it may be inquired, whether light be essentially different from radiant heat? In answer to which I would suggest, that we are not allowed, by the rules of philosophizing, to admit two different causes to explain certain effects, if they may be accounted for by one. A beam of radiant heat, emanating from the sun, consists of rays that are differently refrangible. The range of their extent, when dispersed by a prism, begins at violet-colored light, where they are most refracted, and have the least efficacy. We have traced these calorific rays throughout the whole extent of the prismatic spectrum: and found their power increasing, while their refrangibility was lessened, as far as to the confines of red-colored light. But their diminishing refrangibility, and increasing power, did not stop here: for we have pursued them a considerable way beyond the prismatic spectrum, into an invisible state, still exerting their increasing energy, with a decrease of refrangibility up to the maximum of their power: and have also traced them to that state

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[1] Address of the Vice-president and Chairman of Section B, Physics, American Association for the Advancement of Science, Philadelphia, 1926.

> where, though still less refracted, their energy, on account, we may suppose, of their now failing density, decreased pretty fast: after which the invisible *thermometrical spectrum,* if I may so call it, soon vanished. . . .
>
> If this be a true account of solar heat, for the support of which I appeal to my experiments, it remains only for us to admit, that such of the rays of the sun as have the refrangibility of those which are contained in the prismatic spectrum, by the construction of the organs of sight, are admitted, under the appearance of light and colors: and that the rest, being stopped in the coats and humors of the eye, act upon them, as they are known to do upon all the other parts of our body, by occasioning a sensation of heat.

In spite of this altogether correct point of view, Sir William finally came to the conclusion that there were two kinds of radiation involved. This was because, starting from the extreme end of the invisible region, he found that the intensity, as measured by a thermometer, rose to a maximum and began to fall before the red of the visible became evident, that the heat spectrum continued to fall steadily towards a zero value at the violet end, while the light spectrum increased in intensity to a maximum in the yellow-green region before falling to the same limit at the violet end. He states the case as follows:

> . . . it appears that those who would have the rays of heat also to do the office of light, must be obliged to maintain the following arbitrary and revolting positions: namely, that a set of rays conveying heat should all at once, in a certain part of the spectrum, begin to give a small degree of light: that this newly acquired power of illumination should increase, while the power of heating is on the decline: that when the illuminating principle is come to a maximum, it should, in its turn, also decline very rapidly, and vanish at the same time with the power of heating. How can effects that are so opposite be ascribed to the same cause? First of all, heat without light: next to this, decreasing heat, but increasing light: then again, decreasing heat and decreasing light. What modification can we suppose to be superadded to the heat-making power, that will produce such inconsistent results?

This dual idea of Herschel's had other confirming evidences not so important in themselves but which when taken together strengthened his belief that there were two agencies active, one producing heat, the other light. Herschel's ideas appear to have been generally adopted, though Melloni stated in 1843 that light was "merely a series of calorific indications sensible to the organs of sight and, vice versa, the radiations of obscure heat are veritable invisible radiations of light," a statement which Langley called "the foresight of a man of genius." It was not until Langley's work appeared that the last traces of these ideas disappeared and a single radiation spectrum emerged continuous from the extreme ultra-violet to the end of the infra-red.

Before Langley began his work in 1880 infra-red data were in a somewhat chaotic state. Only by means of prisms could the energy be sufficiently conserved to permit measurements in this region with the detecting systems then available, but these prism spectra were very unsatisfactory since the small refrangibility of these radiations resulted in the entire infra-red field being condensed in a very small space. There was, moreover, no way of translating prism deviations into wave-lengths. Dispersion formulae good in the visible region, gave very discordant results when extrapolated into the infra-red, some, in fact, limiting the possible infra-red spectra produced by prisms to 1 μ. Capt. Abney's photographic results extending to 1.6 μ were questioned on this basis.

Langley's interest in solar radiation led him to attack the problem of infra-red spectra. He felt that his long employment of the thermopile in studying solar radiation might be of assistance to him in the new field. How well justified he was in these expectations, the record of his achievements in this work amply testifies. It is very seldom that a single investigator in a comparatively short period is able to advance an extensive field of research from a state which is largely qualitative to such a high state of quantitative development that a period of forty years does not produce fundamental changes in methods. In the field of the near infra-red, both prism and grating spectra are measured to-day much as Langley measured them. The results of present-day researches in this region are superior to Langley's mainly because time has brought refinements to the methods used by Langley, not because anything radically new had been discovered. Of the new experimental tools and methods employed by Langley the bolometer probably ranks first. With it he was for the first time able to measure the energy of a linear region of the spectrum. It possessed such sensitivity that it could be used to measure even the relatively weak grating spectra, and thereby make possible for the first time the accurate measurement of infra-red wave lengths. This in turn made possible the transformation of prism spectra into normal spectra. He was then able to show that energy curves for the radiations from blackened surfaces at various moderate temperatures showed a shift of their maxima towards shorter wave lengths as the temperature of the sources rose, a relation which developed later in the case of black-body radiation into Wien's displacement law. In these results and in many others of equal importance, the effectiveness of the bolometer was supplemented by other important improvements. The galvanometers were bettered until the later ones showed an increase in sensitivity of ten thousand times the ones first used and were at the same time less erratic. Rock salt prisms and lenses were for the first time given high optical surfaces, capable of producing results in all respects equal to those obtained when glass was used.

To reduce the tediousness of the observations, automatic registration was devised, and methods developed for translating into normal line spectra the bolometric curves obtained from the prism spectrometer. Thus to map out the infra-red solar spectrum was one of the principal aims of Langley's infra-red researches. He succeeded in mapping out the absorption spectrum of the sun as far as 5 μ. The first portion of this spectrum was composed of fine lines which were followed in the longer wave-length portion by bands. These latter were correctly attributed to the water-vapor and carbon dioxide of the air. The lines of this spectrum can not now be identified with the lines of the spectra of any of the many elements which have since been measured. This is probably due to the difficulties arising from Langley's use of a salt prism as a dispersing medium. If a knowledge of the infra-red spectrum of the sun should ever be necessary, it would have to be remeasured by the means and methods now available. This carefully and laboriously measured spectrum has suffered a fate similar to that of many other pieces of work which were intended to be final. In Langley's case as in that of others the methods developed have been the important contributions. They have remained to this day the most effective in general use.

To one interested in exact measurements in this spectral region, the work of Paschen will always stand out as having contributed those refinements of apparatus and methods which were necessary to make infra-red measurements an integral part of spectroscopic data. These data are now used with the same confidence as data from other portions of the spectrum in the development of spectral theories. Paschen's improvements consisted primarily in replacing the bolometer by a linear thermopile which, while not quite so sensitive, was rapid and certain in action and free from many of the defects inherent in bolometers; in improving the galvanometer by increasing both its sensitivity and steadiness and in developing a type of grating spectrograph which preserved the maximum accuracy of grating measurements and was at the same time simple in operation and equally effective throughout the spectrum.

While Paschen made extensive researches in other phases of the infra-red problem, the work of particular interest here is the work on the emission spectra of the elements. It revealed for the first time the full possibilities of infra-red measurement with grating spectrographs, combining as they do maximum dispersion and great accuracy of measurement. His first results went far toward establishing the combination principle of Ritz, since many of the combination lines predicted by Ritz lay in the near infra-red region. With sources of constant intensity an accuracy of one unit in the sixth significant figure was possible in the region from 10,000 to 30,000 Å; with unsteady sources, as open arcs, one unit in the fifth place; while beyond this, a few units in the fifth place to as far as 5 μ. The numerous emission spectra measured by Paschen in the near infra-red region contributed very materially to that extensive development of the series relations which will always be associated with Paschen's name.

Among the new series whose discovery resulted from these infra-red measurements of Paschen and his students are the well-known Paschen infra-red hydrogen series, the Bergmann or Fundamental series for many elements, the principal series of triplets for Zn, Cd, Hg, Mg, Ca, of doublets for aluminum and thallium, the material development of the single line series of Zn, Cd and Hg. In addition, the lines of the first terms of numerous series were found and accurately measured. Standard wave lengths in Hg, Zn and Cd were established.

It is of interest to note that a number of strong combination lines lying between 4 μ and 9 μ, accurately located by combining terms determined by grating measurements, were verified by Paschen and the writer in 1910, using a fluorite spectrograph, the longest of these lines being the 3 d–3 p lines of Na, lying somewhat beyond 9 μ. This is the longest wave length measured up to the present time in emission lines. It is particularly to be desired that other strong combination lines, lying still farther out, be measured since the extension of exact measurement into the far infra-red region requires accurately measured lines for use as standards in calibrations. In his report at Brussels in 1910 to the International Congress of Radiology, Paschen lists some fourteen such lines extending from 9 μ to 33 μ which he considered should be strong lines. The present rules governing the intensities of lines also require these lines to appear with great intensity.

In recent years nearly all, if not all, of the work involving high dispersion and high accuracy of measurement in the near infra-red has been done in America. In the field of line spectra it is now possible to remeasure the emission spectra of many elements and find from two to five times as many lines as were first found. This increased effectiveness is due in part to more sensitive thermopiles and improved radiometers. The principal reason for this advance, however, is the use of echelette gratings and sources of much greater energy.

Accordingly, the speaker and several of his students have remeasured the near infra-red spectra of Ba, Sr, Zn, Cd and Pb with the result that the additional data secured have materially contributed to the completion of the known series relations of the first four of these elements and are contributing towards the establishment of the relations of Pb which are not yet well developed. The earlier work of Randall and Barker on the emission spectra of Fe, Ni, Co, Cr and Mn has recently proven of distinct value in developing the multiplet groups distinguishing the series of these elements.

Recent developments in spectroscopic theory determine the intensities of lines as well as their wavelengths. It has become necessary, therefore, to find accurate methods of measuring these intensities. Without doubt the simplest and also most direct means of determining the intensities of the lines of a multiplet group is that employed in these infra-red measurements where the intensity of a line is taken to be directly proportional to its heating effect, and ultimately to a galvanometer or radiometer deflection. The only requirements are that the lines have sufficient, but not too great, separations and that the source be one of constant intensity.

To a teacher engaged as the speaker was in presenting to a class Nernst's attempt to explain the temperature variation of the molecular heats of polyatomic gases by applying the quantum theory to the rotations of molecules, the appearance in 1913 of Eva von Bahr's work on the absorption of HCl gas at 3.5 μ was most opportune, since the fine structure into which this band was partly resolved seemed to be experimental evidence of the most direct kind that molecular rotations were capable of quantization, a state of affairs difficult to accept at that time even if quantization involving definite frequencies were acceptable. Being engaged at the same time in the measurement of infra-red emission spectra of the elements by means of a grating spectrograph, it was most natural to apply this means of obtaining the necessary high dispersion to the problem of the further resolution of this band into its fine structure, avoiding overlapping spectra, however, by preceding the grating spectrograph by a prism spectrograph of small dispersion. The first work was carried on by graduate students and consisted in examining both the water vapor bands and HCl bands. The water bands analyzed by Sleator proved very complex and too difficult to interpret satisfactorily, but the HCl bands as well as those of other hydrogen halides analyzed by Imes revealed in a striking manner the linear structure of these bands. The lines were narrow, well-separated and of marked symmetry of form and regularity of spacing. As subsequent theoretical development has shown, this resolution was possible because of the small moment of inertia involved and because of the exceptionally simple band structure, for HCl, possessing only two degrees of freedom of rotation, the character of its motion is very much restricted and a single quantum number is required. It is further significant that the change in electric moment with vibrational transition for this molecule is large, which permits intense absorption. The importance of this simplicity of structure of the hydrogen halide bands in the development of theoretical interpretation can hardly be overestimated. The water vapor bands, because of their complexity, have thus far contributed very little to this development, although their fine structure had been observed in detail before that of HCl. It should be remarked in this connection that shortly preceding this, Kemble and Brinsmade had obtained a very good analysis of the HCl band at 3.5μ, using a prism spectrograph instead of a grating.

The HCl spectrum as observed by Imes yielded one other item of exceptional interest, namely, the isotope effect which appears on account of the differences in vibration frequency for molecules in which the Cl atom has different masses. This is the earliest indication of the isotope effect in spectra. With the completion of these first researches in this field, other members of the staff became interested in the problem, and it should be said that most of the subsequent developments of this field of research at Michigan are to be placed to their credit.

Bands which the maximum dispersion of single prism spectrographs had shown as single, or at the most double, have since been resolved into ten, twenty or even forty narrow lines whose wave lengths are measurable with approximately the same accuracy as the lines of an emission spectrum of an element, *e.g.*, within a few Å units. The positions of these bands in the spectrum are assumed to be determined by the energy changes attending transitions between possible vibrational states of the atoms in the molecule while the fine line structure is due in a corresponding way to changes in the rotational states of the molecules. These bands are for the most part associated with changes of the nuclear motions only and their origin is thus simpler than that of bands in the photographic regions, which involve, in addition, electronic transitions. Moreover, since we are here dealing with absorption by unexcited molecules we are certain that these transitions originate in the normal state. The experimental investigation of such spectra, if it can be sufficiently extensive and exact, forms therefore an approach to the study of the positions of the atomic nuclei and their mutual reactions which is certain to give results of great value to the theoretician who has need of simple systems to serve as first tests of his results. The oscillator and rotator are perhaps the two simplest possible systems.

As an example of this, the single missing line in the HCl spectrum was always an indication that the older quantum theory was incorrect. Its absence, on the other hand, has been one of the means of verifying the new theories of Heisenberg and Schrödinger. Also, these theories as applied to the anharmonic oscillator-rotator by Mensing and Fuess, respectively, show that the apparent vibrational and rotational quantum numbers should be $N+\frac{1}{2}$ and $M+\frac{1}{2}$ instead of n and m. The correctness of these results had already been shown by Colby when he established the fact that the very weak band of HCl due to transitions from the first to second vibrational states could be explained only by using $\frac{1}{2}$ quantum numbers in the Kratzer formulae.

The extension of this method of analysis to infra-red bands of other gases has become possible only with the development of more effective methods of observation. The more complex molecules give bands with smaller separation between individual lines and with less simple structure, so that the analysis requires higher resolution. Also many of the bands lie at greater wave lengths where the available energy is very considerably smaller. The necessary increase in sensitivity has been made possible very largely by the introduction of echelette gratings, and the analysis of fine structure for bands out to 15μ is now progressing. Data yielding detailed information regarding molecular configuration are now available for methane, ammonia, ethylene and carbon dioxide.

An echelette grating is one in which the grooves have a triangular form with smooth sides, ruled deeply enough so that none of the original surface remains. The result is very like a broad staircase in appearance. As mounted in a spectrograph, an incident beam normal to one of the oblique surfaces is reflected upon itself with an intensity much greater than would be produced by an ordinary grating and with a wave length determined by the small path difference from step to step. Gratings of this sort were first described by R. W. Wood (1911), his being ruled upon gold-plated copper sheets, but lacking good optical properties because the surfaces were not flat.

At Michigan, due mainly to the perseverance and skill of Dr. E. F. Barker, it has been possible to develop these gratings to a very satisfactory degree, not only for coarse rulings, but even up to as many as 14,400 lines per inch. The surfaces used are ground and polished to optical flatness—aluminum for the coarse spacings and nickel for the finer ones—and the ruling point is a diamond ground to the proper angle. For the earlier experimental work the laboratory was fortunate in having the original Rowland machine kindly placed at our disposal by the department of physics of Johns Hopkins University. While experiments in ruling were under way our own ruling machine was constructed, the design and assembly being largely the work of Captain A. de Khotinsky. This machine is capable of ruling a surface 10 x 20 inches with lines spaced from 25 up to 14,400 per inch.

In view of the fact that methods are required which are still more sensitive than those at present available even when echelette gratings are used, if bands now impossible of resolution are to be studied, and particularly if the work is to be extended into the far infra-red region, it is desirable to consider what, if anything, may still be done. Accepting the radiometer as recently improved, and the linear thermopile-galvanometer combination in its most sensitive form as the receiving devices, what may be hoped for in this direction? While it is possible that some temperature effect quite different from these may be found, much more sensitive than either, it is probable that the great majority of workers are now trying to increase the readings of these two devices by various schemes of amplification.

The enthusiastic confidence which an engineering friend had in the early days of vacuum tube amplification that it was possible to amplify any E.M.F. until the final circuit could deliver power in horse power units has never been realized. It is soon evident to any one trying to amplify the E.M.F. of a thermopile or its current that there are decided limitations to any kind of amplification of these or any other small effects which may be used to register the feeble radiations under examination. These limitations lie in the fact that in all cases there are present disturbances, usually irregular, of the same order of magnitude as the quantities which it is desired to amplify. Under these circumstances amplification is futile. The problem becomes one of suppressing such chance disturbances. To the extent to which this can be done, amplification by any one of a number of means is possible. If, as a recent writer has claimed, the residual perturbations in an amplification system have their origin in Brownian movement, then there is a definite upper limit to the amplification methods of increasing the sensitivity of receiving devices. At present it appears that there are certain advantages to be gained from moderate amplification. These advantages consist mainly in being able to use more robust instruments, of shorter period and less sensitivity, but with an appreciable gain in resulting sensitivity through amplification. To those accustomed to the use of galvanometers adjusted to the point of unsteadiness in order to secure sensitivity, these are very material gains in themselves since they insure quick action and freedom from the vexations of drift and erratic fluctuations. More important still, it appears possible with such systems to devise methods of automatic registration of observational data without that accompanying decrease in sensitivity which formerly was inevitable when galvanometers were made sufficiently steady for registering devices. To be able to record the fine structure of absorption bands automatically, quickly and with no loss of resolution and accuracy will result in shifting the accent in this work from the slow and tedious process of getting data over a comparatively small number of bands to the interpretation of ample data covering an entire system of bands. There is, in other words, the promise here of a revolution in this field of research.

The data obtainable from the near infra-red region should be supplemented, if possible, by data obtained from the far infra-red regions. The near infra-red bands, due as they are to combined vibrational and rotational transitions, suffer perturbations, arising from the mutual reactions of these motions, while in the far infra-red the bands are comparatively free from such perturbations since the molecules are not vibrating, and the rotational transition only is involved. This isolation of the nuclear problem is of particular value in the study of polyatomic molecules, where even the problem of rotation alone may become very complex. The obvious need of such data is resulting in attempts to extend to these regions the methods used so successfully in the near infra-red. The difficulties in the way of such a development are exceedingly great, due mainly to the small amount of energy available and to our inability to isolate the region under investigation. As will be recalled, Rubens and his associates explored this entire region up to 300 μ by a series of brilliant experimental researches among which the discovery of the reststrahlen method of isolation by Rubens and Nichols and the focal isolation method by Rubens and Wood are most prominent. Once isolated these narrow spectral regions were analyzed roughly by the aid of interferometer curves or by coarse wire gratings. If greater dispersion is to be used in this region in an endeavor to reveal the structure of the rotational bands it is evident that the minute amount of energy here available must be conserved to the maximum extent. This at once suggests the use of echelette gratings for the dispersion agent. As a matter of fact the speaker several years ago obtained data extending to 50 μ from gratings of this sort which indicated that they could be used effectively throughout this region. The problem of making such gratings is quite different from the earlier one of making gratings to use in the near infra-red region, since the coarseness of the gratings requires the cutting out of the grooves by steel tools. This means that a very soft metal must be used. At present thin solder surfaces on light aluminum forms are being tried out. This material can not be ground flat so the ruling engine is first used as a shaper, planing a surface as smooth as possible on the solder. Then without moving it, the surface is ruled. To date, only a few coarse gratings of this kind have been ruled. They are being used in an attempt to find and measure the combination lines of aluminum, thallium and lithium, which, as Paschen predicted, should lie in the region between 15 and 33 μ.

So far we have been concerned chiefly with the accomplished facts of experimental and theoretical research in the infra-red region. In conclusion we may be permitted to outline some of the problems of this field of research which are pressing, and to anticipate some of the possibilities which await improvements in technique that appear to be fairly certain of attainment.

In the field of line spectra there is a pressing need for measurements in the infra-red spectrum of those elements whose series relations are now being developed. As already mentioned the possibilities of infra-red methods when applied to the measurement of intensities should be thoroughly tested. When improved technique permits, those weaker sources which give characteristic spectra should be examined. There is finally always the immense field of the far infra-red wholly unexplored as far as line spectra are concerned. Possibly the radiations from the quartz mercury vapor lamp near 300 μ, discovered by Rubens and von Baeyer, is of this type. In any case its structure should be discovered and its origin determined.

In the field of band spectra there are some very obvious advances which await the development of experimental technique. With the increased resolution which will follow increased sensitivity, the fine structure may be determined for a large number of bands which now just escape us. This is particularly promising in the study of polyatomic molecules, at least for those with an approximate axial symmetry. The new wave mechanics of Heisenberg and Schrödinger give us for the first time satisfactory expressions for intensities. Considerable progress has already been made in the study of the symmetrical rotator and, with the slight experimental data now at hand, gives great promise. The Heisenberg theory gives two alternatives between which it can not decide for the quantum numbers describing the rotation. They may be either integral or half quantum numbers. By the Schrödinger theory they should be whole numbers.

No decisive data for symmetrical molecules is now available, but it appears that the measurement of the infra-red absorption spectra of such molecules might be decisive. There is no doubt that a more careful study of intensities must be made, a rather exacting problem where the fine structure is not easily resolved. Such measurements should not only yield information concerning the molecule in question but also serve as tests for certain details of the wave mechanics itself.

Not only are the intensities important, but also the shape and breadth of the lines have theoretical significance. This phase of the subject is but slightly developed and so far agreement with experiment is not good.

Bands in the far infra-red can not be expected from molecules which have no permanent electric moment. This probably excludes such a molecule as methane, whose rotation is by no means clearly understood. There is, however, a large number of gases for which data in this region will be invaluable. The problem of normalization of the rotation of HCl has been definitely settled by its far infra-red band. Water vapor has a far infra-red absorption spectrum, the intricacy of which must be ascribed to its lack of symmetry and has not been satisfactorily interpreted. Symmetrical rotation should be investigated here as soon as possible. The most promising for this purpose is the ammonia molecule.

The infra-red region is not simply an extension of the spectrum at the long wave-length end. The data which it furnishes are not simply more data of the kind to be obtained in the other parts of the spectrum. The band spectra of the near infra-red region are different in type from those of the far infra-red and both are different in character from the bands in the photographic regions. The information to be obtained from these infra-red spectra is not to be found elsewhere. Their resolution and measurement is therefore a problem not only worthy of our endeavor but necessary for the development of the theories of band spectra and the related problems of molecular structure.

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SCIENTIFIC SERVICE THAT THE NATIONAL FORESTS MIGHT BE RENDERING

WITH the network of good roads that has been constructed within the last few years rapidly extending itself over every part of this country, scientific men and nature lovers are faced by the fact that we shall soon have no wild places and no areas left in their natural condition except barren and inaccessible mountain tops and waterless deserts, unless reservations are set aside for preserving the natural conditions.

In fact, at the present time the only places of any considerable extent that are intended to be kept in a natural state are the national parks, and as time goes on these are being managed more and more as recreation resorts, their natural condition being sacrificed to the entertaining of large crowds of tourists. The destruction of timber in building and grading the broad roads for high-speed traffic, the wear and tear caused by the tens of thousands of visitors in the places most famous for their scenery, the camps, hotels, garages, etc., necessary to serve and accommodate them, the parking of thousands of cars and other accompaniments of the constantly growing tourist traffic are disastrous to the natural conditions in those regions of the parks where the scenery is most remarkable, while those regions of them that lie off the routes of tourist travel are not safe from destructive exploitation legalized by acts of Congress slipped through without the public understanding their purpose or effect. Not a session of Congress passes without attempts to trim off portions of the parks containing timber or other commercially valuable resources, and too often they are successful. Three of the national parks have been treated this way during the past year (1926). From state and local parks we have little to hope in the way of preserving natural conditions. They are usually too small and are commonly managed chiefly as recreation resorts; moreover, they always suffer under the frequent changes of administration that occur in local governments.

If natural conditions are to be preserved it must be accomplished in places that are not resorted to by crowds of tourists, a condition that the national parks with their wonderful scenery can not meet. Also it is usually necessary that the reservations should be of some extent in order that the destructive effects of exploitation on adjacent lands may not reach completely over them. Land used for grazing, and least of all land used in forestry operations, as is the case with the national forests, does not remain in a natural condition, though it may serve well enough as a preserve for the protection of birds or animals that can adapt themselves to the changed conditions. It is especially the very old trees that have taken centuries to grow and would take centuries to restore, that make the difference both from a scenic and scientific point of view between a primeval forest and an ordinary farmer's wood lot or the young growth of cut over lands.

This leads us to wonder why a few square miles out of the immense extent of the national forests