

majority of animals and plants so far studied. But because linkage and crossing-over have been added to our equipment, and because with knowledge of these we can apply the laws of heredity over a much wider field, is this a reason for stating that because "the systems of structure are different the rules of heredity are different"? It is quite true that the information concerning the arrangement of the elements of heredity has helped us enormously to a fuller understanding of other types of heredity than those that Mendel first discovered, but of course Jennings does not mean to say that this wider knowledge made Mendel's laws more unintelligible, although a casual reader might interpret him in this way.

On the contrary, Mendel, by great insight in interpreting the results of experiments that were carefully and deliberately planned to determine how individual characters are inherited, arrived at two generalizations that are fundamental for all later work. His method was one that a physicist might have been proud of, and without his discoveries I think we might still be floundering around, as had the earlier hybridists, because they did not understand how to ask an intelligent question in order to get an intelligent answer. For it is not every experiment, so called, that will give the answer sought. Nature is sometimes as oracular as the priestess of Delphi. It took even physics a long time to find out how to question nature intelligently. In finding this out it was slowly discovered that certain methods of approach were more satisfactory than others. I have indicated what those methods are, and I think that we biologists can not do better than to borrow them from the physical sciences.

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SOLAR RECORDS IN TREE GROWTH¹

THE freedom from undergrowth of the pine trees of northern Arizona and their exposure to the characteristic droughts of the country first suggested to the writer the idea that their variations in growth had a climatic and solar origin. Accordingly a long search was made for evidence of such relationship, which has resulted in the identification, dating and measurement of several hundred thousand rings in something under a thousand trees scattered widely about this and other countries. Many interesting results have been obtained and an extensive technique of ring-study has been developed. Of that technique

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the most important line has been the study of cycles which might have a solar cause.

It is no surprise that variations in climate can be read in the growth rings of trees, for the tree ring itself is a climatic product. In the spring the pines put on a rapid growth of soft white tissue, which continues till lack of moisture, through temperature or dryness, diminishes the growth and stimulates the tree to prepare for winter by putting on a red lignite ring. The growth gradually stops and in sufficiently dry or cold weather comes to an end till the warmth and moisture of spring revive it.

If successive years were exactly alike, the rings would all be of the same size with some alteration with age or injury. But successive years are not alike, and in that difference some factors appeal strongly to the trees. In northern Arizona, with its limited moisture and great freedom from pests and with no dense vegetable population, this controlling factor is identified as rainfall. So it is not astonishing that the pine trees, as tested near Prescott, Arizona, show a correlation with rainfall between 80 per cent. and 85 per cent.

The extent of the dependence of this southwestern rainfall on solar changes is still a point under discussion. Helmann found the sunspot cycle in the rainfall of North Germany, and it has been identified in many places, most notably perhaps in the well-known thirty-five-year Brückner cycle. But the strongest bit of evidence of solar effect on climate is in the trees themselves, for in this region where the trees are specially sensitive to rainfall they show the eleven-year sunspot cycle in a striking manner, and they show it in a double-crested curve just as the rainfall itself in southern California shows it. This has been brought out recently in a dramatic manner. From the start the sunspot cycle was sought in the Arizona pines, and during long parts of their growth it seemed perfectly evident, yet for scores of years it failed, and in 1914 I very nearly gave up the idea that the trees really show it, because near 1700 it failed entirely. Finally in 1919 (Carnegie Publication 289) I gave the facts about it, saying that from 1660 to 1720 the sunspot curve "flattens out in a striking manner," and again, "the sequoias show strikingly the flattening of the curve from 1670 or 1680 to 1727." Early in 1922 I received a letter from Professor E. W. Maunder, of England, calling attention to the prolonged dearth of sunspots between 1645 and 1715 and saying that if there were a connection between solar activity and the weather and tree growth, this extended minimum should show in the weather and in the trees. On receipt of the letter this period was immediately recognized as the interval referred to in which there was entire failure in attempting to trace

solar effects. A more recent review of the eleven-year period in those trees confirms its well-marked existence from before 1400 to the middle of the seventeenth century. Soon after 1700 it reappears, but not in complete form until the latter part of that century.

The test was then carried to the sequoias. It was found that the slow-growing sensitive upland trees were the ones which best displayed the solar cycle, and also that the interference by other cycles was such that the double period of about twenty-three years was a more satisfactory manner of tracing the changes of the solar period. When these conditions were allowed for, the same result was obtained as before from Arizona.

In 1922 or before, it was noticed that when the eleven-year cycle disappeared from the trees near 1700, two other cycles, one of ten or twenty years and the other of fourteen or twenty-eight years, became prominent in its place in the Arizona pines. Soon after it was noticed that the Vermont hemlocks show the same change at that time, and so also the sequoias of California. And then it was observed that these three basic cycles appear generally in the western trees; these are, first, eleven and one half or twenty-three years; second, ten or twenty years; and, third, fourteen or twenty-eight years. And these three cycles were recently confirmed in a study of 52,000 measures of rings in 305 trees scattered over ten western mountain states. And there is reason to think that all these cycles come from the sun, for at different times the sunspot cycle itself has changed to one or the other of them. For example, from 1748 to 1788 there were four complete cycles of ten years each; from 1788 to 1830, forty-two years, there were three complete cycles of about fourteen years each. It seems at least likely that these other two cycles, found in western trees with extraordinary persistence, are also of solar origin.

In the recent extensive study of cycles in the western yellow pine, it was noted that the moist coastal regions show the eleven-year cycle more generally than the drier interior sections or the Rocky Mountain area. This agrees with the result of ten years ago in which the wet-climate Scotch pines of North Europe, especially near the Baltic Sea, showed a direct single-crested sunspot cycle having a remarkable resemblance to the curve of sunspot numbers. Their growth gave the solar changes with an accuracy exceeding that of any trees of the southwestern area. Recent study confirms the further statement that this is a wet-climate phenomenon. But it is not yet clear just what causes this accuracy of record in the wet-climate trees. It seems probable that the wet-climate trees follow the sunspot cycle more closely than do the weather elements in which they live, and it is per-

haps safe to repeat the suggestion made by the writer in 1922 that there may be some more direct line of cause and effect from the sun to these trees than we have taken into account, such, for example, as radiation (possibly of short wave length), that is especially favorable to trees growing generally under cloudy skies. In tree groups along the Atlantic coast of this continent, the eleven-year cycle is also prominent, but it has a phase displacement of two or three years.

The pages above give the probable forms which solar records take in tree growth. It was expected by the time of this writing to have a fairly complete historic study of solar variations, but the formal work along that line has had to be postponed for a time. In a general way it is safe to say that the sunspot cycle and its double and triple value are very general. The double value has persisted in Arizona for five hundred years and in some north European localities for the century and a half covered by our tree groups. The triple period, essentially Brückner's cycle, has operated in Arizona for the last two hundred years and in Norway for four hundred at least. A hundred-year cycle is very prominent throughout the three thousand years of sequoia record and also in the five hundred years of yellow pine. It is still uncertain whether the eleven-year cycle can be judged by the variations in its double value, which, from the absences of certain interfering periods, is more easily traced through long periods. But a very incomplete review of the sequoia record suggests that from 1300 B. C. to well after 1000 B. C. the eleven-year cycle was well developed; then it slowly decreased. From 300 B. C. on it was increasing and was very conspicuous during the first two centuries of our era. Then it decreased and from 400 to 650 A. D. was only occasionally evident. From 650 to 850 or 900 it seems fairly continuous. Then it appears only occasionally until about 1250, when it again becomes fairly continuous, except for the changes in the seventeenth century above noted.

Such then are the solar records so far translated from tree growth, whose complete understanding, it is believed, will give us extensive historical information of this sort in many different parts of the world.

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THE SIGNIFICANCE AND SCOPE OF THE IDEA OF FREQUENCY IN PHYSICS¹

It has long been recognized that exponential (periodic) solutions of certain partial differential equations are essentially necessary when such equa-

¹ Paper presented at the Philadelphia meeting of the American Physical Society.