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THE CONTRIBUTIONS OF ASTRONOMY TO CIVILIZATION

THE principal duty imposed upon the president of the Pacific Division is the delivery of an address at the annual meeting. In some respects this duty is an embarrassing one for the present incumbent. This is preeminently an astronomical occasion, and your president is not an astronomer. With no original message of his own, he can perhaps best fulfill his obligations by reminding those who are gathered here of some of the great contributions which astronomy has made to civilization.

If the earth were alone in the universe human life could not exist. With the sun to give essential warmth and light, life would be possible; but imagine if you can how the progress of mankind would have been retarded if there were no stars, or if the pioneers of astronomy had failed to discover how to use their apparently uniform rotation as a measure of the flow of time and the axis of this rotation as a standard of direction. The north star was a faithful guide to the traveler, and without it Columbus might well have hesitated to embark on his perilous journey in search of a new world. The first astronomers, without instruments, must first have noticed the rotation of the fixed stars about the axis passing through Polaris, then the orderly annual precession due to the motion of the earth in its orbit. The seemingly erratic motions of the planets must have puzzled them, but in time the orderly sequence of their motions with respect to the earth was recognized and correctly described in Ptolemy's theory of epicycles. As time went on, accumulated observations and deductions therefrom gradually made clear our relations to the solar system. Copernicus revived the bold guess made by others centuries before, that the earth and planets revolve about the sun. Galileo, with the enlarged field of vision due to the telescope, found reasons to support that guess, and Kepler formulated the laws which almost exactly describe the motions of the planets in elliptic orbits around the sun. Newton proved that the same force which causes bodies to fall to the earth, causes the moon to revolve about the earth and the earth about the sun. This discovery made celestial mechanics an exact science.

Mathematical astronomy has made it possible to establish standards of time and to make exact surveys of the earth, and enables the navigator to find his position and determine his direction at sea. When his observations are made impossible by cloud or fog and he is compelled to rely upon the uncertain aid of compass and log, the sailor realizes what he owes to astronomy.

In making an exact chronology and exact surveys of the earth possible and in facilitating maritime intercourse between nations, astronomy has rendered a practical service which all must recognize, and which is of inestimable value to civilization. But civilization means more than material welfare. It means the extension of man's range of thought beyond his immediate surroundings and the constant effort to discover his relations with the universe; it means an understanding of the phenomena of nature on this earth and in all the heavenly bodies accessible to our sight; it means the projection of our mental vision backward to the remote past and forward into the distant future; it means an understanding not only of the evolution of man and of society, but of the evolution of worlds; it means the formulation of a consistent hypothesis regarding time and space and their relation to each other, and it means a constant effort to develop the esthetic and spiritual values of life, which must be closely associated with the physical phenomena which affect our lives and thoughts and which are the direct objects of scientific study. It may mean other things as well, but to all of these elements of civilization at least astronomy has made notable contributions, and upon it alone must we depend for our knowledge of what lies outside this tiny atom which we call the earth.

By successive steps Ptolemy, Copernicus, Kepler and Newton made clear the relations of the earth to the solar system. Later observations on the orbits of double stars showed that the law of gravitation holds good to the remotest regions visible through the telescope. The spectroscope shows that the sun and the stars are made of the same materials as the earth, thus proving the material unity of the universe. The spectroscope and the telescope have enabled us to extend our observations to any heavenly body from which light brings its message, and slowly but with increasing certainty the astronomer is learning to interpret these messages and to journey in imagination to far distant worlds.

The spectroscope tells us how fast the stars are moving in the line of sight with respect to the earth, and by analyzing such results, Campbell and others are able to tell us how rapidly and in what direction the solar system is traveling through the stars. Furthermore, spectroscopic observations, interpreted with the aid of researches made in the physical laboratory, give definite information concerning not only the constitution, but also the temperatures and the densities of stars. The angular diameters of many stars have been determined by Michelson's interferometer method, and in cases where the distances are known the actual diameter can be calculated. So far away are they that only in comparatively few cases can their distances be determined by triangulation, using the diameter of the earth's orbit as a base line, but Adams has shown how we may determine their distances, no matter how great these distances may be, from definite and easily observed relations between their apparent brightness and the peculiarities of the lines of their spectra.

Through the action of gravitational forces, heat and chemical and radioactive transformations, every body in the universe is undergoing ceaseless change. If we can in the case of any one body discover its original condition and establish the sequence of its physical states until its life of physical activity has run its course, the problem of stellar evolution is solved, for we may be sure, from the substantial identity of constitution of all the heavenly bodies, that they will all pass through the same cycle of experience. The human race can not exist long enough to follow the life history of any one star, but from the study of individuals in different stages of development, we can, with the aid of established physical principles, infer the sequence of their stages of development.

To Kant and to Laplace we owe the first rational hypothesis of stellar evolution, but they had at their command insufficient data to establish their nebular hypothesis on a sound basis. Within the last few years astronomers have accumulated a great mass of material which gives a more secure foundation for a consistent theory of stellar evolution. In the case of hundreds of stars much is known concerning their distances, their sizes, their densities and their temperatures. From the laws of physics we know the general trend of the changes which must take place in any star. If at first it is a highly rarefied and diffuse mass of vapor at a low temperature, gravitational forces will cause its gradual condensation, and this will produce an elevation of temperature, just as the air in an automobile tire becomes hot as it is compressed. As the temperature rises, the vapor will first become red hot and ultimately white hot. After the density reaches a certain stage, condensation will proceed more slowly. When the loss of heat by radiation exceeds that produced by compression, the star will cool in reverse order from white to red heat. After it has contracted to the solid state, like the earth, the production of heat by condensation will cease, while cooling by radiation will continue, until the star loses its luminosity. This process of condensation and cooling will be extremely slow, and Eddington has pointed out that it may be prolonged by internal development of heat due to superchemical transformations made possible by enormously high temperatures and pressures. These may cause the formation of one element from another by the aggregation of atoms, a reversal of the radioactive process of disintegration. If such be the sequence of changes in any star, it is evident that it must pass through the red stage twice, the first time while rising in temperature toward the white state and again while cooling. It is an established fact that there are many huge dark nebulae which may be the original stuff of which stars are made, and that the red stars can be separated into two well defined classes of giants and dwarfs, differing enormously in size and density but little in mass. These large differences in size are not found in the white stars, which are all, according to this hypothesis, in the same stage of development. It is mainly to Russell that we owe this hypothesis of stellar evolution from a dark diffuse nebula passing by condensation through the giant red stage to the white stage, then back to the dwarf red stage, ultimately to become a dark solid body. This theory, while not entirely free from criticism, is a beautiful and logical picture of stellar evolution. What may be the final destiny of the dark bodies which are the final product, we can only guess. Hundreds of thousands of such dead and invisible worlds must exist, most of them perhaps destined to wander through space for all time, but some of them may, by collision with other bodies, be again resolved into glowing vapor and begin a new cycle of existence.

The distances and the magnitudes of the stars and the duration of their stages of development are beyond the grasp of human imagination. On the other hand, recent developments in physics show that in all probability every atom is the analogue of our solar system, with electrons revolving like planets around a central nucleus charged with positive electricity, in orbits so small and in periods so short as again to elude our imagination. The one element that we can grasp in comparing an atom with the solar system is the relation of the parts of each to the whole, not the absolute values of the magnitudes and the periods of time in each.

The idea of relativity, first applied by Newton to motion and extended by Einstein to include all the relations of space and time and matter, is one which is perhaps destined to exert a greater influence upon thought and conduct than the idea of evolution, and it is to astronomy that we must look for the final tests of its validity.

Newton clearly conceived the idea of relativity of motion as we actually observe it, although he believed that in fact there might be in the universe some fixed point of reference, if we could only find it. We may measure the velocity of a body with respect to the earth, but the earth itself revolves on its axis and at the same time moves around the sun. The latter is not at rest with respect to any other body, and the stars travel in chaotic fashion. If we consider the earth to be at rest, the planets move around it in epicycles. If we take the sun as the fixed center, the planets move around it in ellipses. We have no means of knowing, or even of imagining the true orbits of these bodies in space. Newton expressed the belief that "absolute space, by virtue of its own nature and without reference to any external object, remains the same and is immovable." Although many held to this view up to our time—perhaps some still do—there seems to be no way by which the absolute motion of bodies through this immovable space can be determined. For a time, however, the general acceptance of the wave theory of light revived the hope that such absolute motion might be detected. The waves with which we are most familiar, such as those of water and sound, are periodic displacements in a continuous medium, and it seems impossible to imagine any waves without some medium through which they may be propagated. This gave rise to the hypothesis of a universal ether, the medium of light waves and electro-magnetic phenomena. Various attempts have been made to determine the motion of the earth through this hypothetical stationary ether, the most famous and significant of which was the Michelson-Morley experiment, first performed nearly forty years ago and repeated several times, always with a negative result.

To illustrate the effects which might be expected, let us consider a familiar example of wave motion, that of sound, which is transmitted through the atmosphere. In 1915, from my home in Berkeley, I could see the flash of fireworks in the Exposition grounds in San Francisco, and from 49 to 54 seconds later the sound of the explosion could be heard. The difference in time was due to the varying direction of the wind. The velocity of sound in the air was in each case the same, but the air itself was transported with the wind, sometimes toward me, sometimes in the opposite direction. The apparent velocity of the sound was the resultant of these two velocities. Similarly, if an observer is stationed on a moving train, the velocity of sound waves through the fixed atmosphere appears to him to be greater if the train is moving toward the source, less if it is moving away, and since the velocity of the sound waves in the stationary atmosphere is known, the velocity of the train with respect to the atmosphere can be calculated. Similarly, if light waves are propagated in a stationary ether, and if the earth moves with respect to the ether, we would expect the measured velocity of the light to vary with the direction of motion of the earth in such a manner that the motion of the latter with respect to the fixed ether could be calculated.

The Michelson-Morley experiment, carried out with the utmost precision, showed that in all positions of the earth in its orbit the observed velocity was the same, both in the direction of the earth's motion and at right angles to this direction. It was thus proved that the velocity of light appears to be the same to all observers, whatever may be their velocities relative to each other or to the earth. We are forced to the conclusion that it is impossible to determine uniform absolute motion through space by any optical method, and no other method can be imagined.

The experimental conclusion that the velocity of light is the same for all observers, regardless of their relative velocities or directions of motion, a fact so utterly at variance with results observed in the analogous case of sound, seems, from the standpoint of our experience, to be a logical contradiction. In seeking for an explanation, we are driven to the conclusion either that the motion produces a change of length in our apparatus and measuring instruments in the direction in which they move or that the perceptions of space and time are different for observers moving relatively to each other. The first of these alternatives was suggested by Fitzgerald and elaborated by Lorentz. The failure of the Michelson-Morley experiment could be accounted for if the dimensions of the apparatus used were shortened in the direction of the motion of the earth. This seems a plausible suggestion, because we know that a material object moving through the air would be slightly shortened in the direction of the motion by air pressure. In the latter case, however, a steel bar would be shortened less than a wooden bar, whereas Michelson and Morley used a number of materials in their apparatus, all with like result. It would, moreover, be a strange coincidence if the contraction should in every case, for all velocities and for all substances, be exactly of the magnitude to produce compensation.

Einstein in his earlier special theory of relativity sought a more general explanation which leads to the surprising conclusion that there is nothing absolute in our measurement of space and time intervals, but that they will be different for two observers moving with uniform velocity with respect to each other. A fundamental postulate of classical mechanics is that the time interval between two events and the distance between two points in a rigid body are the same whether measured in the system to which they belong or observed from another point of reference moving with respect to the first. All our measurements of time and space depend directly or indirectly upon the use of light signals, and hence will be dependent upon the facts that the velocity of light is finite and its apparent velocity the same for all observers. These measurements depend upon sense perceptions which may not correspond to the real world in any absolute sense. It is not possible here to enter into a detailed discussion of this subject, but Einstein showed by simple and irrefutable algebraic calculations that if an observer regards himself as at rest, the dimensions of objects and the durations of events in a system moving relatively to him will appear to be changed. For example, if the aviator in a rapidly moving aeroplane waves his arm, it will appear shorter when in the horizontal than in the vertical direction, and the duration of the gesture will appear to increase with the speed of the aeroplane. The aviator is not aware of these changes; on the contrary, to him objects on the earth appear to be shortened and intervals of time lengthened. In each case, the calculated expression for the shortening is identical with the Fitzgerald-Lorentz contraction formula. Which observer is correct in his conclusions? The answer is that both are. It is not necessary to assume any real contraction in an absolute sense in either case. Because the velocity of light is the same for all observers, the time and space intervals which have certain values for an observer in one system will not appear to be the same to an observer in another system moving with respect to the first. The differences are very small unless the relative velocity is very great, and we can not hope to observe them in ordinary cases. Cathode rays and the beta rays from radioactive substances, and electrons rotating in atomic orbits, move with speeds approaching that of light, and in these cases some of the consequences of the special theory of relativity have been verified. One of these consequences is that the mass of a body is not constant, but varies with the speed, so that mass is also relative.

Thus it appears that not only uniform motions, but lengths, intervals of time and masses are relative and will appear different to two observers moving relatively to each other. Moreover, it follows from the same considerations that it is impossible except in special cases to determine whether two events are simultaneous or not. Newton believed that "absolute, true and mathematical time flows in virtue of its own nature uniformly and without reference to any external object." We now realize that this, like his conception of absolute, immovable space, is a metaphysical conception, corresponding to no physical reality which we can ever hope to establish.

From such considerations, it appears that our last hope of any absolute knowledge of the physical world is destroyed. With no objects or only one object in the universe, space would be meaningless. With the appearance of two objects at a measurable distance apart space is created, but this distance is not the same for different observers. With no object, or one object subject to no internal changes, time would be meaningless, there would be no past, no future, only an eternal present. If changes take place in an object, or if another object moves with reference to it, time is created, but the rate of flow of that time will appear to be different to an observer in another moving system. We speak of the uniform rotation of the earth, but if its period should change and the period of revolution of the earth in its orbit should change in the same proportion, we would never know the difference, except that our lives might appear to be lengthened or shortened. If the rate of our bodily processes also changed in the same proportion, our lives might be lengthened or shortened a thousand fold, and we would never know it.

That there is a real world outside of ourselves, no physicist doubts, but it is full of illusions and we can learn little about it with our unaided senses. When we supplement these senses with such aids as the telescope, the microscope, the spectroscope, the photographic plate and the instruments used for detecting electric and magnetic effects, we can learn much concerning things lying outside the range of our sense perceptions, such things as ultra-violet and infra-red radiations, X-rays and many electromagnetic phenomena. Most of our scientific knowledge, especially that concerned with atomic phenomena, is based not directly on sense perception, but on inferences so logical that we feel satisfied with their validity, but after all they are only inferences.

The aim of scientific inquiry is to obtain descriptions of the external world which will be the same for all observers, that is to say, what are called invariant relations. The special theory of relativity shows that we can not obtain invariant relations of physical phenomena in terms of space alone or of time alone. Minkowski first called attention to the fact that the two are inseparable. Physical phenomena are events which occur at given points of *space* which may be specified by rectangular coordinates measured from a definite point of reference, and at a definite instant of *time*. Minkowski showed how to construct the mathematical expression for a combined time-space interval between two events which would be an invariant for all axes of reference moving with uniform velocity with respect to each other. In a two dimensional plane space, the square of the hypothenuse of a right-angled triangle is equal to the sum of the squares of the sides. If the hypothenuse is the distance between two points on a plane, it is invariant, but there are an infinite number of pairs of sides the sums of the squares of which will be equal to the square of this distance, all depending upon the orientation of the axes of reference. In three-dimensional space the square of the diagonal is equal to the sum of the squares of the sides of a right-angled solid, which again may have an infinite number of values. Time is not space, but it is one of the elements which fixes an event. Minkowski represents the joint space-time interval between two events by the length of what he calls a world line, which, by analogy with the length of the diagonal of a right-angled solid, is so defined that its space is equal to the sum of the squares of the three rectangular space coordinates of the event and the square of the time interval multiplied by a coefficient which we need not consider here. The length of a given world line is invariant, but associated with it are an infinite number of possible space and time coordinates, which may be regarded as the projections of the world line on variously oriented axes. Thus various values of the space intervals and time intervals measured along these axes may be associated with the length of a given world line between two events. This four-dimensional continuum fits the case of special relativity. For example, two events, such as flashes of lightning, may take place at different points at different times. To two observers in relative motion with respect to each other, the distance and the interval of time between these two events will appear different, but the expression for the combined space-time interval, the length of the world line, will be the same for all observers. By the application of this principle, all the laws of physics can be expressed in invariant form for all systems of reference having uniform rectilinear motion with respect to each other.

We need not vex ourselves with the futile attempt to visualize this apparently four-dimensional world. It is not four-dimensional in a purely spatial sense. It happens that the three dimensions of space are evident to our senses. We also think we have a definite notion of the duration of time, but it is not a notion which we can visualize, so that we need not expect that the combination of the time dimension with space dimensions will be evident to our senses. In fact, even the third dimension of ordinary space is to some extent an inference. A totally paralyzed person with one eye would perceive the external world only by means of a two-dimensional image thrown on his retina. He sees little more than he would in a photograph on a flat surface. With two eyes he would get an inkling of the third dimension through perspective, but only by moving his hands and legs and going from place to place could he perfect his notion of three dimensions. We must reconcile ourselves to the fact that our sense organs are too imperfect for us to perceive all that goes on in the world around us. It is futile to attempt to describe a symphony to one who has been deaf from birth or color to one who has always been blind. Yet it is possible to give to the deaf and the blind an idea of the sound waves and the light waves which may produce the sensations of sound and color in others more highly endowed. This analogy may reconcile us to our inability to visualize the four-dimensional world of Minkowski, and yet allow us to believe that the mathematical expression for the lengths of his world lines correspond to physical realities.

To prepare our minds for the reception of Einstein's later theory of general relativity we must submit to a still greater strain upon our credulity. We must not only accept the idea of four-dimensional time-space in a mathematical sense, but we must consider the consequences of a possible curvature of this space. On a plane surface the square of the diagonal of a right-angled triangle is equal to the sum of the squares of the sides. Such a space is called Euclidean. We have a similar expression for the diagonal of a cube in three-dimensional space, which is likewise Euclidean. By analogy, we may call Minkowski's four-dimensional space Euclidean if the square of the world line is equal to the sum of the squares of the space and time coordinates. But consider a curved surface, such as that of a calm lake. It appears to us to be plane, but we should find that if the lengths of the sides of a right-angled triangle are measured on this surface, the sum of the squares of the sides will not be equal to the square of the hypothenuse. The mathematician can prove that this indicates a curvature of the surface, and he can determine from the measurements how great the curvature is. Such a surface is not Euclidean. In Minkowski's four-dimensional time-space world, the sum of the squares of the space and time components of an event is ordinarily equal to the square of the length of the world line. In cases where this is not so, but one or more of the squared terms are multiplied by a factor different from unity, we may say that this space is curved. The shortest line between two points in a plane surface is a straight line. The shortest line between two points on a spherical surface is a curved line, part of a great circle, and is called a geodesic line. By analogy, we may consider that in Minkowski's four-dimensional world a world line is curved when the space is curved, and we may call it a geodesic line. We may represent the space-time interval between two successive ticks of a moving clock by the expression for the length of a world line. In curved space the successive world lines representing intervals between ticks would when joined, end to end, not lie on a straight line.

It is the later general theory of Einstein which is of most interest to us here, because its tests are entirely astronomical. The special theory of relativity applies only to uniform motion. In the case of accelerated motion there seems to be an absolute element. Acceleration is the rate of change of velocity. We can not detect our uniform motion through space, for example on a ship moving in calm water, but if the ship is suddenly stopped we become very much aware of the change in velocity. If we apply a mechanical force, such as a direct push or pull, to an object, its motion is accelerated. Conversely, if we observe that a body is accelerated, we infer the action of a force. An unsupported body falls to the earth with accelerated motion. We attribute this to a hypothetical force called gravity. The earth is subject to a uniform centripetal acceleration toward the sun, which we attribute to the same force. Gravitation has always been one of the great mysteries of the physical world. If a stone is whirled around at the end of a string, it is easy to visualize the force as due to the direct pull of the string. In what way does the sun exert its pull upon the earth? Action at a distance is repugnant to our minds, and it does not help us to imagine the ether as the medium through which this force is exerted, for earth and sun alike seem to slip freely through this ether. We might as well try to imagine the ocean pulling two ships together. We do not know nor can we ever expect to know the mechanism of gravitation. The Newtonian law merely describes the effect of this hypothetical force. If it turns out that the Newtonian law is an inadequate statement of observed facts, we shall need to correct it, and this is what Einstein has done in his general theory. We are satisfied to accept the Newtonian law because we have grown familiar with it, although we do not understand its physical basis in the least. We hesitate to accept the Einstein law, which is neither more nor less mysterious than that of Newton, because we have not become accustomed to it, yet in all probability the next generation will accept it without question and think that it understands it.

The basis of the general theory of relativity is the principle of equivalence. If we imagine a closed box in space at a great distance from attracting masses there will be no gravitative forces to consider. A man standing on the floor of the box will exert no pressure on the floor, in other words will be devoid of weight. If the box is suddenly accelerated upward, there will be a pressure created similar to that of which we become aware when in an elevator which suddenly starts upward. An apparent gravitational field is created which can not be distinguished from a true gravitational field. The two are equivalent. In general, therefore, we may say that when one reference system is accelerated with respect to another—say a ship with respect to the earth—forces are created which are equivalent to those produced in a gravitational field. For example, if the motion of the ship is suddenly checked, passengers are thrown forward as though a gravitational force pulling them toward the front of the ship had been created. A beam of light from an outside source passing through the accelerated box at right angles to its direction of motion would apparently be bent toward the floor. The principle of equivalence leads us to the conclusion, therefore, that a beam of light would be deflected in a gravitational field. A projectile moving uniformly in the same direction would appear to fall in a parabolic path to the floor, as a projectile falls to the earth. If the light waves behaved in exactly the same manner, without loss of speed, we should get the so-called Newtonian deflection of .84 seconds of arc for a beam of light passing near the sun. But the curvature causes a change of the direction of the wave front, corresponding to a progressive decrease in velocity in approaching the sun. From this we may conclude that in a gravitational field there is a departure from the law of constancy of velocity of light assumed in the special theory of relativity, and that the change of direction of the wave front, corresponding to the case of ordinary refraction, will cause a further bending of the beam toward the sun. This causes the Newtonian deflection to be doubled, so that the predicted displacement is 1.75 seconds of arc, a prediction brilliantly confirmed by Director Campbell.

Futile as it may seem to try to understand first principles, we can not avoid speculating as to the explanation of the relative acceleration between the earth and the sun which we attribute to the force of gravitation. Newton's first law of motion, the law of inertia, asserts that a body on which no force acts, moves uniformly in a straight line. We can imagine conditions, however, in which this is not possible. Consider a two-dimensional surface such as that of a sphere to which a body is restricted, although it is free to move in any direction in this surface. In such a case if the body is set in motion, it will continue to move with uniform speed along the closest approximation it can make to a straight line, that is along a geodesic line. If we observe the motion of the body from a point outside the system and are unaware of the constraint to which it is subjected we will conclude that it is subject to an attractive force directed toward the center of the spherical surface. As a matter of fact there is no such force in this case, but the motion is determined solely by the curvature of the space in which the body moves.

When in the four-dimensional world of Minkowski the square of the length of a world line is equal to the sum of the squares of the one time coordinate and three space coordinates, we say that this space is Euclidean, that is, without curvature. It is at least formally analogous to the three-dimensional case in which the square of the diagonal of a cube is equal to the sum of the squares of the sides. In his general theory of relativity, Einstein assumes that in a gravitational field, space is not Euclidean, but curved. In such a case, as we found in the analogous case of a two-dimensional spherical surface, the coefficients of the squared terms, the sum of which is equal to the square of the world line, are not equal to unity. In such a curved space the natural path of a moving body is not a straight line, but a geodesic line. Thus the effects which we have attributed to gravitation are not dynamical, but are a direct consequence of the geometry of space. The earth moves around the sun not because it is attracted by a force, but because the law of inertia constrains it to move along the geodesic lines in the curved space surrounding the sun. By properly choosing the coefficients of his squared terms, Einstein has been able to obtain a law of gravitation which is identical with that of Newton at a distance from matter, but introduces a small correction term in the immediate neighborhood of large masses.

It is as fruitless to speculate upon the physical meaning of this apparent curvature of the space in the neighborhood of massive bodies as it is to speculate concerning any other theory of gravitation. All that we can expect of any hypothesis regarding fundamental things is that it shall lead to a mathematical law which shall as simply and exactly as possible describe observed facts, and additional weight must be attached to such hypotheses when they suggest the prediction of previously unsuspected facts and these predictions are verified by observation. These conditions are fulfilled by Einstein's theory. It exactly accounts for the anomalous rotation of the major axis of the orbit of Mercury, which is greater than that demanded by the Newtonian theory. It predicts a deflection of light waves passing by the sun which is double that demanded by the Newtonian theory, and this prediction has been verified. Another consequence of Einstein's theory is that any kind of a clock runs more slowly in a strong gravitational field. An atom emitting light vibrations is a clock, hence we may infer that the atoms in the solar atmosphere emit light waves of smaller frequency and greater wave length than the same atoms on the earth. This prediction has not yet been verified, as the predicted change of wave length is small and the disturbing factors in the solar atmosphere great, but it will not be surprising if this final verification of Einstein's epoch-making theory is found.

To sum up, we have seen that astronomy has rendered man great practical service; it has enlarged his knowledge of his environment near and far; it has given him some notion of the relation of himself and his earthly home to the universe; it has given him glimpses into the remote past and ground for speculations as to the distant future; it is unfolding the story of the evolution of worlds, and now it is unraveling some of the mysteries of time and space which have so long baffled the human mind. In addition, by adding to our general knowledge and developing the powers of the imagination, it has, in common with other sciences, directly and indirectly enlarged the ethical and esthetic values of life. Conduct is also relative; what is a virtue to-day may be a sin to-morrow. Good intentions alone can not carry us far on the road of righteousness. To avoid blind groping, we must have that understanding of the relations of our conduct to our happiness and that of our fellow men which only the most complete knowledge of our earthly environment can give. Moreover, appreciation of the esthetic values which add so much to the joy of living seems dependent upon knowledge and the training of the imagination which it gives, for ignorant savages seem blind to the beauties of nature and unresponsive to the appeal of art.

Generous as the contributions of astronomy to civilization have been, there is promise of more to come. The universe is either finite or infinite, but our imaginations can grasp neither alternative in terms of the old ideas of space and time. On the basis of the general theory of relativity, it seems possible that astronomical observations may reveal to us a universe which is finite and yet unbounded, a self-contained universe keeping intact its store of matter and of radiant energy, with no infinite ocean of empty space around it, for there can be no space where there is no matter. This is the hope that is held out to us by Einstein and his co-workers, and to the astronomers we must leave the task of confirming that hope.

E. P. LEWIS

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ROBERT WIEDERSHEIM

BY the death of Robert Wiedersheim, long the professor of anatomy in the University of Freiburg i/Br., another milepost has passed in the history of the comparative anatomy of vertebrates. Five days past his golden wedding anniversary, already afflicted by an inflammation of the lungs which was not supposed at the time to be serious, he fell asleep. In his hand he held the book with which he was beguiling himself when he died, "Die Geschichte der Anatomie."

Dr. Wiedersheim was born at Nürtingen am Neckar in the Würtemburg Black Forest, April 21, 1848, the son of a physician there. Fourteen days after his birth his mother died, and young Wiedersheim was brought up in the household of his grandfather, Immanuel Friedrich Otto, owner and proprietor of a cotton mill at Nürtingen. After attending the gymnasium at Stuttgart, with a short time in Lausanne, he studied further at the universities of Tübingen and Würzburg, obtaining his M.D. at the latter place, January 27, 1872. Here also he accepted an assistant professorship under Kölliker (1872–76), refusing a call to the University of Tokio as professor of anatomy there.

In the winter semester, 1876–77, Wiedersheim came to Freiburg as the assistant of Professor Alexander Ecker, whom he succeeded there as professor of anatomy at the latter's death in 1887. Here he remained until his retirement in 1918, leaving in his position Dr. Eugen Fischer, who is there at present.

While still an undergraduate he met his wife, Tilla Gruber, daughter of a Genoese banker, a German residing with his family in Italy, and married her July 7, 1873. In 1878, he built his summer home on the shores of Lake Constance, his beloved Villa Helios at Schachen near Lindau, which served him during many vacations. Here he retired after he left Freiburg, and here he died.

Wiedersheim, although he could never be induced to cross the ocean, travelled in Europe extensively, and made one short journey to Algeria. He visited England several times, especially to attend the Darwin Centenary in 1909; he travelled extensively also in France and Italy, including Sicily.

Aside from his work in human anatomy, which made him famous all over Germany, and brought students from other universities to Freiburg to take their anatomy with Wiedersheim, he gave a course in comparative anatomy, and received private students from other countries.

In 1882 appeared his "Lehrbuch der vergleichenden Anatomie," which he soon followed by a "Grundriss," explaining the same things in a more concise manner. This latter book he much preferred, and brought out several editions, the last (7th) appearing in 1909. It was his custom to keep a manuscript of this on his desk, making constant additions and revisions for use in newer editions. It soon became one of the largest and best of the text-books of comparative anatomy. In special monographs his work, though not extensive, was yet so carefully done that each was a classic. We need only mention "Das Kopfskelet der Urodelen," his work on the ear of the Ascalaboten, and the anatomy of Salamandrina perspicillata and Geotriton fuscus.

It is a well-recognized truism that, in the World War, the intellectuals suffered most. On April 14, 1917, three hostile bombs dropped from a British airship caused Wiedersheim's laboratory to burst into flames. It was totally destroyed. The minds of men were at the time aflame; there were ugly rumors of a similar treatment of British hospitals, there was a feeling of the need of reprisals. We are sure only that in this conflagration the great anatomical collection started by Alexander Ecker, his world-famous skull collection, some 200 microscopes and numberless anatomical charts, among others some from Professor Wiedersheim's skilled fingers, were almost wholly lost. Yet in relating these incidents Wiedersheim uttered no word of blame or censure, one of the last illustrations of the kindness of his disposition. Surely, in the death of Robert Wiedersheim the world lost far more than a great anatomist; to many he was a devoted friend. With