science and the modern world

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One of a series of lectures presented at Georgetown University, Washington, D.C. on the occasion of its 175th Anniversary, October 1963 to May 1964

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Introduction

During the period September 1963 to December 1964, Georgetown University commemorated the 175th anniversary of its founding by presenting a series of special lectures in the various disciplines appropriate to a university. Among the subjects covered, in separate and coherent series, were the humanities, the arts, medicine, law, and religion. One of the series, entitled as a group, "Science and Society," is represented by this book.

The ten papers presented here must be looked at in context: an effort was made to present to a largely lay audience a cross section of those aspects of recent advances in science and technology that were considered to have the most striking or inclusive effects on man's view of his world, on desirable public policy, and on man's anticipations as to how further advances and applications of these advances were likely to change his environment.

Clearly, so ambitious an undertaking could not be carried out within the compass of ten brief lectures. Within a general structure, it was necessary to use a sampling technique. The general plan was adopted of having three lectures representative of the philosophical sector, three of the public policy structure, and three which would partake of the nature of extrapolations into the future. A tenth lecture was later added which could be considered to fit equally well into the second or third of these categories.

Within the philosophical sector, it was considered that the great effect of science during the immediate past had been in the fields of astronomy or astrophysics, and biology. It was also considered appropriate to balance accounts of these fields with a prudent appreciation of the limitations of science. At a time when even man's ethical and aesthetic value systems have been attributed to the effects of natural selection, it seemed important to be reminded of the extent to which value systems and the affective contents of experience cannot rest on a material base, and as well, of the limits that such barriers as considerations of attainable energies set beyond which scientific experiment cannot possibly go.

In the public policy sector, lectures on the practical uses of atomic energy, and on population trends and population control, were joined to a general discussion of the relationship of government sponsorship to scientific exploration.

In the realm of extrapolations to the future the talks were planned about materials and instrumentation, the development of the computer sciences, and biology and medicine, as the centers from which the most drastic general effects would come.

It is one thing to conceive a grand outline. It is much more difficult to bring it to fruition. The list of the titles of the lectures, and of the distinguished speakers who spoke on each of the topics, gives a clear indication of what was intended. A perusal of the texts will show, however, that many of the speakers either restricted themselves to particular aspects of the topics suggested by the titles or, in one or two cases, departed from them substantially. While the grand design may have suffered from these changes, they added depth where they reduced scope, or introduced an unexpected emphasis on timeliness which was very appropriate in the year of the anniversary. Thus, to cite a single example, Professor Dobzhansky's lecture dwells at some length on aspects of racism, which was very much on the minds of all audiences at the time of his lecture.

The thanks of the University are due to each of the ten speakers who made this series the success that it was. All of them are active men with heavy demands on their time. The delay in publishing this volume is a natural result of that fact. The material is of such a nature, however, that its timeliness has not been impaired by the extra year that has elapsed from the date when the earliest publication could have been expected. Thanks are due also to Mrs. Harriet Hubbard for her patient care in preparing the manuscripts for publication.

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New Developments in Our Knowledge of the Universe

RECENT DEVELOPMENTS in cosmology are the result of the impact of a mixture of disciplines on astronomy. It is the introduction of radio astronomy that is responsible for the most remarkable of these developments. And the prosecution of radio astronomy entails electrical engineering, the use of bulldozers, the methods of dealing with mud and electronic physics as well as astronomy.

I shall assume that you are familiar with the term "galaxy" and that perhaps you know what the spectrum of a luminous object is. But in case you have forgotten, I will remind you that if white light is passed through a prism, or some equivalent device, a band of colored light is obtained, with violet or ultraviolet at one end, blue, green, and yellow in between, and red at the other end. When the light comes from an astronomical object, such as an entire galaxy or an individual star, certain black lines are also present and they are known as the spectral lines, which are, so to speak, the footprints left by the chemical elements found in the outer layers of the luminous object. In some spectra however there are also emission lines—that is to say brilliant lines—which arise because a certain type of atom is very common in the outer layers of the object. These atoms are themselves emitting light and, therefore, they produce an enhancement of the spectrum at that particular point.

A very important datum for cosmology is the so-called red-shift, namely, a displacement of all the spectral lines towards the red end of the spectrum. This occurs in a way which compels us to say that the displacement means that the galaxies are moving away from our own. It is a Doppler shift. The method of measuring the red-shift is the following: The wavelength, in the laboratory, of a spectral line being λ, the Doppler shift increases the wavelength to $\lambda + \delta\lambda$. Then the red-shift, which is usually noted in the literature by the letter z, is the ratio of the increment of wavelength $\delta\lambda$ to the original or laboratory wavelength λ, so that $z = \delta\lambda/\lambda$.

This is what astronomers observe, though they like to describe it, just to confuse the issue, by multiplying z by the velocity of light c. Thus there is obtained what has been called a ficitious or representative velocity. I shall avoid this device and use z instead. For the nearer clusters of galaxies, the Virgo cluster for instance, z is small, equal to about 0.004. The largest red-shift which has been measured, in an object to which I shall presently refer, is as large as 0.46. There is no theoretical reason why red-shifts equal to 1, or greater than 1, should not occur, and presumably some day objects with red-shifts greater than 0.46 will be identified and they will no doubt be galaxies of some kind.

In a general way it may be said that the larger the red-shift, the farther away is the object in question though distance is not simply proportional to red-shift. Up to May 1960, the largest red-shift that had been measured had been observed by spectroscopic means in the Hydra cluster of galaxies, and the amount was a little larger than 0.2. But in May 1960—you are no doubt familiar with this charming story—Dr. Minkowski at Mount Wilson and Palomar, who was about to retire, had his last 10-day run on the 200-in. telescope, and he decided to devote it to the study of a certain object he believed would be interesting from the red-shift point of view. This object was suggested to him by the work of radio astronomers. It is No. 295 in the third Cambridge catalog, and is therefore known as 3C295. Minkowski, talking to the radio astronomers at the California Institute of Technology, concluded that 3C295 was an intrinsically strong radio source, even if it did not appear strong in terrestrial radio telescopes. The reason why it did not appear strong, Minkowski conjectured, was that it was very remote.

The radio astronomers had fixed the position of 3C295 to within a small area of the sky. The area was not so large that the 200-in. optical telescope, with its small field of view, could not examine it in a reasonable time. The first thing Minkowski noticed was that 3C295 appeared to be the brightest galaxy of a group of about 60 galaxies. A spectrum with a 9-hr exposure showed one single bright emission line, and very little else. Minkowski decided that this emission line was the well-known line of singly-ionized oxygen. But in order to achieve this interpretation it was necessary to suppose that the red-shift was 0.46. Admittedly, even by cosmological standards, this result was a trifle uncertain, to say the least. There was one single identified spectral line and, on this basis, a red-shift of more than double what was known before had been obtained. However, there were the other members of the cluster to which 3C295 appeared to belong, and therefore Minkowski asked his colleague Dr. W. A. Baum to study some of the other members of the cluster by a different technique which I will not describe. And, happily, as a result of Baum's studies on, I believe, three more of the galaxies of the cluster it was revealed that indeed the whole cluster had a red-shift of 0.46. By the aid of radio astronomy a great leap forward into the remoteness of space had thus been taken.

There is a much closer object known as Cygnus A which is also a radio source and is a galaxy of the same general type as 3C295. And from the optical point of view there is no difficulty in saying that both objects are galaxies, though perhaps one might think that Cygnus A is not a very neat and orderly kind of galaxy, but one in which unusual events are taking place.

Radio astronomy has done more than this, however, during the past year by drawing attention to very much more remarkable kinds of objects. These objects, of which four or five are certainly known and many more are no doubt waiting to be discovered, are strong radio sources. But they possess the curious feature that, unlike 3C295, Cygnus A or many of the other known moderate or strong radio sources, they are found in isolation and are not members of clusters of galaxies. Moreover, their optical images on the photographic plate look just like the images of stars.

One of these objects is 3C273 which, in a photograph, looks like a star, except that it does have a narrow filament of gaseous material apparently stretching away from the stellar-like main body. The optical spectrum of the latter has been interpreted by Maarten Schmidt, an interpretation which leads to a red-shift of 0.158. This would correspond to a distance of the order of 1.6 billion light years and this in turn indicates that the central body is 40 to 100 times more luminous than 3C295 or Cygnus A, themselves no mean radiators of light. Moreover, Harlan Smith has found that 3C273 had been photographed on plates at Harvard for 70 years or more. Examination of this long series of plates showed that the emission of light was variable with roughly a 10-yr period. Now and again, notably in 1927-29, the object suddenly increased in luminosity. At the maximum of such a flash, 3C273 is 1600 times as bright as the brightest supernova. The flashes last from 2.8 hours to 12 days. Another remarkable fact about 3C273 is that its radio emission comes from two separate centers; one is close to the main body, the other lies near the far end of the jet of gas. This was established by Hazard and his colleagues in an very elegant lunar occultation observation carried out in Australia.

Another object of the class is 3C48, whose optical spectrum is interpretable if a red-shift of 0.37 is assumed. The distance is of the order of 3.6 billion light years and