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A Critical Analysis of Eddington's Concept of Space

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A CRITICAL ANALYSIS OF EDDINGTON'S CONCEPT OF SPACE

By

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VITA

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TABLE OF CONTENTS

TABLE OF CONTENTS
(cont'd.)

CHAPTER I.

INTRODUCTION.

This thesis aims to examine the works of one of our greatest contemporary mathematicians and scientists, Sir Arthur Stanley Eddington, and from the statements in his works to obtain his concept of space, and subsequently to compare it with the Scholastic thesis concerning space.

There are several initial objections that need to be removed before we can begin to inspect Professor Eddington's writings. The question can well be asked, "What does he hold, and how can we know it?" It seems useless to rely on his words alone, since, as any scholar knows, there are sections of science that defy a true explanation in words because they can be portrayed only via the symbols of mathematical equations. Moreover, some are said to challenge the trustworthiness of Eddington's expositions. Is he a valid representative of modern science? And is he to be treated as physicist, astronomer, mathematician, or philosopher? And as for the topic of space itself, how can anyone imagine that the space of Eddington the relativist can be subjected to analysis in ordinary language?

These are indeed difficulties, and grave ones, yet I believe that with close adherence to the topic of this thesis a course can be steered between the extremes of a too sketchy presentation and a digression into the entire Einsteinian theory of relativity. Let us consider the difficulties one by one and thus clearly set forth what is the field of this thesis.

First of all, I believe that Professor Eddington is generally accepted as a valid representative of the school of modern scientists who hold and are attempting to broaden the applications of the Einsteinian theory of relativity. Born in 1882 in Kendal, England, he was educated at Cambridge, and in 1913 became Plumian Professor of Astronomy there. His principal researches have been on the motion of stars, stellar evolution, and relativity. From his first paper in 1906 to the present he has written an impressive series of scientific works whose undoubted merit and scholarship have been acknowledged by both his friends and critics. The Encyclopedia Brittanica thus appraises him:

> Eddington grasped the significance of the theory of relativity at an early stage of its development, and by means of articles, books, and lectures gave a clear exposition of the theory.[1]

L. Susan Stebbing, Professor of Philosophy at the University of London and author of Philosophy and the Physicists, a book

1 The Encyclopedia Brittanica, Encyclopedia Brittanica, Inc., New York, 1929, Fourteenth Edition, XIX, 94.

directed in great part against Eddington's philosophical views, has this to say in her preface:

> Sir Arthur Eddington stands in no need of commendation by me. Indeed, for me to praise him is almost an impertinence. But so much in this book is adversely critical of his philosophical views that I wish to record how great is my admiration for his scientific work.[2]

From the viewpoint of a Scholastic philosopher it is interesting to note how many Scholastic authors refer to his works either in direct quotations or in their bibliographies; Bittle, Boyer, Maritain, Nys, Saintonge are a few. Monsignor Sheen in his Philosophy of Science again and again bases his evaluation of modern scientific views on quotations made from Professor Eddington's books to such an extent, indeed, that he refers to no other scientist more often than to Eddington. Consequently, with authority of this sort we may dismiss the objection that Eddington has failed accurately to portray the basic aspects of scientific theories in his more popular works, and that he has sacrificed correct facts, difficult to conceive, for incorrect but easily comprehensible circumlocutions. That, being aware of this danger, he took precautions against it, is evidenced by his words in the preface to one of his "popularizations," The Nature of the Physical World.

> It would not serve my purpose to give an easy introduction to the rudiments

2 Stebbing, L. Susan, Philosophy and the Physicists, Methuen, Ltd., London, 1937, ix.

> of the relativity and quantum theories; it was essential to reach the later and more recondite developments . . . . A scientific writer in forgoing the mathematical formulae which are his natural and clearest medium of expression may perhaps claim some concession from the reader in return. Many parts of the subject are intrinsecally so difficult that my only hope of being understood is to explain the poimts as I would were I face to face with an inquirer.[3]

And Monsignor Sheen's remarks are highly apropos:

> But once the new physicist thinks of the universe in terms of electrical charges and 'invisible' forces, mathematical symbols become the logical instrument of description. Modern physics -- in the sense, at least,of some of its popular exponents -- deals with a symbolical world, and since the mathematician's stock in trade is symbols, he becomes the important organ of expression.[4]

Sir Arthur Eddington's books are the following:

1. Space, Time, and Gravitation (1920),
2. The Mathematical Theory of Relativity (1924),
3. Internal Constitution of the Stars (1926),
4. Stars and Atoms (1927),
5. The Nature of the Physical World (1928),
6. Science and the Unseen World (1929),
7. New Pathways in Science (1933),
8. The Expanding Universe (1933),

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3 Eddington, A.S., The Nature of the Physical World, The Macmillan Company, New York, 1935, vii.

4 Sheen, Fulton J., Philosophy of Science, The Bruce Publishing Company, Milwaukee, 1934, 46.

9. Relativity Theory of Protons and Electrons (1936), and
10. The Philosophy of Physical Science (1939).

Of these books this thesis will consider particularly the popularizations, not delving into the advanced mathematics of the second and ninth titles. Science and the Unseen World, a series of lectures on the relation between science and religion, will also be omitted from our discussion since it contains no material pertinent to the subject of this thesis; it is a very elementary presentation of a few major facts of physics and chemistry as far as its scientific passages are concerned. We shall, however, devote a special chapter to The Nature of the Physical World because the book has a special philosophic purpose and deals most extensively with our topic. Eddington's views in the remaining works, particularly respecting "curved space," will be treated in a second chapter. Finally, having explained the Scholastic doctrine of space, we shall compare it with Eddington's concept.[5]

We must not forget that Sir Arthur was first an astronomer, whence through his interest in higher astronomy it was inevitable that he became a physicist; but the astronomer and physicist of our day must also be mathematicians; hence, Eddington's third title. Now, it is regrettable that he has assumed the fourth title of "philosopher." Like the bulk of our contemporary men of science he has achieved admirable re-

5 I use the word "concept" as synonymous with the Scholastic idea objectiva, the content of the subjective idea.

sults in his fields, but, led astray by his brilliance in the mathematical field, he has extended his mathematics equivalently into a universal philosophy that is definitely idealistic and places the existence of objects in our minds solely because of our minds.[6]

Monsignor Sheen in particular finds fault with the school of scientists to which Professor Eddington belongs, for adopting the mathematical description of phenomena as the ultimate explanation in physics.[7] Likewise, there is the statement of Miss Stebbing, who notes the same undue assumption.

> But his greatness as a scientist is to be judged not by the books I have discussed but by his strictly scientific works that stand in as much need of being interpreted for the benefit of the common reader as do the works of any other scientist. In the books with which I have been mainly concerned, Eddington has set forth for the benefit of the common reader an interpretation of recent developments in physics, including his own contributions in this domain. His interpretation, however, suffers from very serious omissions and from an altogether misleading emphasis. One of the most striking omissions is his failure to give the common reader any indication as to the way in which physical measurements are in fact obtained. This omission enables him to produce the paradox that physics is solely concerned with pointer readings. His very skilful . . . mode of presentation has enabled him to throw

6 Cf. his last five chapters in Eddington, The Nature of the Physical World, and also Msgr. Sheen's evaluation in Chapter 4, Philosophy of Science.

7 Sheen, Ch. 3, 4, 10 passim.

> the emphasis upon just those elements which are most essential for the development of his metaphysical views.[8]

Let us note very carefully how this criticism hangs together with the present thesis. Miss Stebbing asserts interpretation is needed for Eddington's strictly scientific works, not for the popularizations; but critic though she is, she implicitly grants that recondite experiments and concepts can be sufficiently explained in those popularizations. Contrariwise, what she does complain of in these popularizations is that they lead to philosophical error. Now, in obtaining and appraising Eddington's concept of space, we intend to abstain from his use of it when it appears as a background for his philosophical views in certain chapters of his books. We intend to analyze the concept only in its scientific meaning. We will treat of Eddington the scientist; Eddington's philosophical system would have to be the subject of a lengthy and detailed appraisal, far out of the range of this thesis.

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8 Stebbing, xi.

CHAPTER II.

THE NATURE OF SPACE ACCORDING TO SCHOLASTIC PHILOSOPHY

Before any investigation concerning so vast and difficult a subject as "space" can be undertaken, the topic must be limited very minutely. Some idea of its idifficulty and amplitude can be gained by considering the items that are directly related to our topic: from a mathematical and scientific viewpoint, there is mathematical infinity, Euclidean and non-Euclidean geometry, the relativity and quantum theories, vacua, the aether, and astronomical data; from a philosophical viewpoint there are the questions of a plurality of worlds, philosophical infinity, the immensity of God, and the problems of place, time, and local motion. All these topics are related to the question, "What is space?" In the course of their discussion and study throughout the centuries they have led men to elaborately constructed and sometimes wierd systems, all in an attempt to solve this ever-perplexing problem that has baffled great minds, but which, we believe, Scholasticism has handled successfully.[1]

1 Cf. Bittle, O.F.M. Cap.,-Celestine N., From Aether to Cosmos, The Bruce Publishing Company, Milwaukee, 1941, 147 ff. Also cf. Nys, D., Cosmology, tr. by Sidney A. Raemers, Vol. II, Part III, "Space," The Bruce Publishing Company, Milwaukee, 1942.

Let us consider the Scholastic explanation of space as a basis for our comparison of Professor Eddington's spatial concept.[2] At the outset we must distinguish our terms and understand that the space of mathematics -- the simple extension of geometry -- is not now under discussion. Rather are we subjecting to analysis the common concept of space and attempting to determine to what it corresponds in reality.

When as children we began to become aware of objects around us by means of sense-perception, our concept of these objects represented them as extending in three dimensions. Experience showed us that all objects extend in these three dimensions, whence we obtained our abstract idea of extension. Simultaneously we found that location was ascribed to things by reason of their relation to some point of reference or to some quasi-vessel that contained them. All things extended had to be contained in and bounded by some larger receptacle, and when no material receptacle was at hand, we began to use the idea of space to represent the receptacle. Thus, our spatial concept was at last formed. Our mind by abstraction from the extended things we experienced conceived a universal three-dimensional container for any and every material thing. Naturally a container of itself must be empty -- otherwise, how could it hold any other object? Here was the note of emptiness, and with this the evolution of our general concept of space ceased. Today the man on the street

2 For the authoritative Scholastic doctrine on space, the manuals listed in the Bibliography, Section C, were consulted.

adopts this concept, using it mainly as a means to express emptiness and nothingness.

As philosophers we now take this common notion of space and subject it to further and minute examination. New properties, hitherto only implicit, now begin to appear as we study the universal space that is here and there and everywhere and even outside the universe. The primitive notes of emptiness (at least relative and ultimately absolute emptiness) and of the universal receptacle stand out first. We must say of place that a place is located according to a greater and more universal place until ultimately there is a limit to "places," and that is the limit of our universe; but we cannot assert this of space, for even outside our universe there is still "empty space." Before the world was created, empty space had to exist, and if the world and all creation were annihilated, only space would remain. Moreover, our universe floats, as it were, through an immense sea of space -- a sea that must be conceived as homogeneous, infinite in extension, all-pervading, lest material bodies be presumed to be excluded from "somewhere"; a sea that cannot consequently expand or contract or move in any manner whatever and that never changes.

All these notes follow once we pause to consider the metaphysical consequences of the universal receptacle. Concerning these notes, upon reflection we find full assent in consider-

ing the common concept of absolute space. Summarizing, space must be a universal receptacle that is everywhere, even outside our universe; that is eternal, uncreated, and indestructible, immobile, unchanging, all-pervading, non-material, and subject neither to compression nor expansion.

A pressing question immediately follows: granted that these properties are the content of our idea of space, does absolute space exist with these properties as an objective reality outside our mind? Apparently either space is wholly a fiction of the mind or it is wholly existent with all these notes as a reality. Many a philosopher has been caught on the horns of this dilemma, for the choice of either disjunction involves embarrassing difficulties. The Scholastic system takes a middle course, distinguishing in order to show a third possible answer to the puzzling question, and the answer this time is that space is a conceptual being with a foundation in reality, a mental abstraction based on the reality of bodies. Where bodies exist, they exist in "real space." All other space into which bodies can be created is "possible space." The combination of real and possible space is called absolute space.

The Scholastics argue thus. This absolute space cannot be an objectively real being, for not only are its notes contradictory, but the conditions requisite for its existence postulate an infinite regression. For example, while being

eternal, non-material, infinite, uncreated, and "everywhere," simultaneously it must possess indefinite extension and immobility; but the unique being who is eternal, infinite, uncreated, and omnipresent is God Himself, who can by no means be supposed to possess an indefinite extension or immobility or the negation of perfections (emptiness and nothingness) that the concept of space implies. And "if space was first required in order that extended bodies could be placed in it, this very space (if it were an extended thing) would require another containing vessel as a condition for its existence; and so forth indefinitely."[3]

This argument does not hold for the aether postulated by the exact sciences, inasmuch as aether of itself is always inside the universe. It is consequently a limited, extended, and created being. Above all, it is postulated solely in order to remove the nothingness that would be in our universe were space alone to exist wherever we are unable to find solid matter.

The Scholastic notion that space is a conceptual being with a foundation in reality outside the mind is obtained by a further examination of the spatial concept. That space is not a real being has already been proved; that it is purely a conceptual being has been disproved by our analysis of the evolution of the concept from direct experience. These two extreme hypotheses can be combined, however, so that our intellect is

3 Hoenen, S.J., Peter, Cosmologia, Gregorian University, Rome, 1934, 93.

said to conceive space as a real being even though space cannot exist as a real being outside the intellect in view of its contradictory notes. The properties of the spatial concept are not such, however, as appear in purely mental beings like "wooden stones," where the individual notes exist totally separated in different, distinct beings. These properties are abstracted from reality when we first arrive at the concept of space as "abstract extension considered as a receptacle for bodies."[4] They can be combined to express a judgment respecting real things. If we say, "Space of three dimensions exists," we mean that bodies having three dimensions exist. Thus, the extension of real bodies and the possibility of having additional extended bodies constitute our "foundation in reality."

It is not essential in this thesis to cite in detail the opponents of this Scholastic doctrine. They can be classed in the two groups of ultra-realists and ultra-subjectivists. Among the realists space was a "sui generis" being distinct from all other physical realities. This was the opinion of the early Greek Atomists. Newton, Clarke, Fenelon, and Bgyma identified it with God's immensity; Spinoza and all pantheists deified it. Locke and the moderns, Riemann, Gauss, Helmholtz, Fechner, Weber, and Mueller -- almost all of a scientific or mathematical school-- defended it as "absolute space." Among the subjectivists Kant was foremost with his theory that space is a subjective, a priori

4 Bittle, 156.

innate sense-form that is present in the mind before all perception, making perception possible. Also to be classed in the subjective group are Leibniz, Hume, Berkeley, Hegel, Spencer, and Samuel Alexander (with his "Space-Time" evolution), but an exposition of these adversaries' views would lead us too far afield.[5]

5 Nys summarizes the doctrines of all adversaries of the Scholastic thesis very carefully and at some length.

CHAPTER III.

THE NATURE OF THE PHYSICAL WORLD

The first of Professor Eddington's books to be considered is The Nature of the Physical World, which was published in 1929 and presents substantially the same material as that delivered by Sir Arthur in a course of lectures at the University of Edinburgh two years earlier. I have chosen to consider it in the first place because no other work of its author is quoted more extensively in the literature on the subject. Probably the book has been given this importance because of the fact that one-third of it is devoted explicitly to an exposition of Eddington's philosophy, while the other section aims to interpret recent findings in physics so that this interpretation can serve as a basis for understanding the philosophical theories that follow. As mentioned in the Introduction, our task is to arrive at Eddington's scientific concept of space, not at the concept as it appears when made an integral part of his philosophy.

At the very beginning of the book Professor Eddington inducts his reader into the first mystery (of the "mysteries" he will subsequently describe in terms of the relativity theory) by comparing two tables -- or rather one and the same table considered first in the ordinary manner and then in the scientific.

> This table is a thing; not like space, which is a mere negation; not like time, which is -- Heaven knows what . . . .[1]

> My table is mostly emptiness. Sparsely scattered in that emptiness are numerous electric charges rushing along with great speed. . . . It is nearly all empty space, space pervaded, it is true, by fields of force, but these are assigned to the category of influences; not things.[2]

Here at first sight Eddington would seem to be considering space as a sort of vacuum, as nothingness itself. However, before we pass judgment on these early passages, we must consider later parts of his book that amplify the meaning of his words considerably. From these later excerpts it is clear that his use of "nothingness" as synonymous with space is only in the wide popular sense. Now we begin to hear the physicist himself.

> Space and time are words conveying more than one meaning. Space is an empty void; or it is such and such a number of inches, acres, pints .... When [the physicist] speaks of space, it is always the inches or pints that he should have in mind. It is from this point of view that our space and the space of the nebular physicists are different spaces. To avoid possible misunderstanding it is perhaps better to say that we have different frames of space -- different frames to which we refer the location of objects.[3]
>
> Space is/like whatever we find from experience it is like. So space is like a network of distances.[4]

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1 Eddington, A.S., The Nature of the Physical World, Cambridge University Press, 1929, ix.
2 Ibid., x.
3 Ibid., 13.
4 Ibid., 81.

Thus, in common parlance space signifies nothingness, but for the scientist space becomes something strictly and solely quantitative. It is measured extension; and more, too, it is a locans universale, a reference point that gives objects their location. The reference "frames" of space are of course a comparison with Cartesian coordinates.

> We must rid our minds of the idea that the word space has anything to do with void. . . . In any case the physicist does not conceive of space as void. Where it is empty of all else there is still the aether. Those who for some reason dislike the word aether scatter mathematical symbols freely through the vacuum and I presume that they must conceive some kind of characteristic background for even these symbols. I do not think that anyone proposes to build even so relative and elusive a thing as force out of entire nothingness.[5]

Absolute emptiness, then, cannot be postulated in our universe. The measured extension already encountered now is described as a receptacle for the substratum that must underlie and pervade all objects, and through which all forces must work.[6]

These excerpts cover quite well the first of Eddington's usages of the word space. It is "unfilled space in a man's body"[7] and"non-empty space" filled by "mass, momentum, or inertia,"[8] where "unfilled" and "empty" signify only relative

5 Ibid., 137.
6 Ibid., 31.
7 Ibid., 1.
8 Ibid., 153.

and not absolute vacua. The complete absence of solid matter still permits the presence of the aether. Indeed, this presence is postulated as necessary if we wish to remain logical.

> We postulate the aether to bear the characters of the interspace, as we postulate matter or electricity to bear the characters of the particles.[9]

But there are two other usages of space according to Eddington -- the "curved space" of the universe and electronic microcosms, and "space beyond space." Here precisely begin our difficulties, for we must enter into the nature of non-Euclidean geometry, on the mathematics of which rests the Einsteinian theory of relativity of which Sir Arthur is a prime exponent. A mathematical or philosophical exposition of the theory of relativity is, of course, outside the scope of this thesis; consequently, we will merely describe it as a physico-mathematical theory referring to the measurement of motion, space, and time, that makes this measurement different for each observer according to his "location" in space and time. The matter of non-Euclidean geometry, however, bound up rather closely with our subject, calls for a more lengthy digression and explanation.

Geometry (in Eddington's own words) "is the science of the measurement of space around us."[10] The ordinary geometry which describes the spatial relations of our world is called

9 Ibid., 31.
10 Ibid.,162.

Euclidean after its early Greek founder, Euclid. His system is logically coherent, and is built up on certain fundamental assumptions called axioms, assumptions so fundamental as to be unprovable. In the last century geometers, by refusing to accept one or other of these axioms evolved new geometries, intrinsecally consistent and possessing novel properties. There are two main types of non-Euclidean geometry. Against Euclid's axiom that through a point outside a line one and only one line could be drawn parallel to the given line, Lobatschewsky assumed that an infinite number of parallels could be drawn. Riemann assumed that no parallels could be drawn. It is this latter Riemannian geometry that Eddington uses in his exposition of the theory of relativity, and Eddington's curved space is a method of expressing a mathematical symbol of Riemannian geometry.[11]

Whereas Euclidean geometry was the bible of classic nineteenth century physics and postulated infinite space extending in the three spatial dimensions of common experience, the non-Euclidean geometries show the possibility of a space with an indefinite number of dimensions that are finite in their extension but unbounded. This is a case where by misunderstanding these extra mathematical dimensions a person could rashly charge equivocation in statements such as Professor Eddington has made -- not realizing that if there is a given mathematical

11 Ibid., 120.

equation (as in Solid Analytic Geometry, for example)

$$Ax + By + Cz = k,$$

which defines a straight (Euclidean) line in the three dimensions of length, width, and depth, where each dimension is expressed by a variable, a "line" in any number of "dimensions" could be defined merely by adding any number of new variables. Of course, such a "line" could not be imagined, but mathematically it would be a line in "n" dimensions, obtained as a purely mathematical device in working out certain formulae.[12]

This is given only as an a pari argument. It is not by any means an example of the higher mathematics of Professor Eddington and his confreres. It is merely to point out that the mathematician's dimension is a mathematical determination worked out similarly as our ordinary three dimensions, and that the failure to be able to imagine such a space of "n" dimensions cannot be used as an argument against it.

> Because we don't know whether or not space of four dimensions is possible, the same affirmation must be made concerning non-Euclidean geometry of three dimensions; we do not know whether or not it is possible.[13]

Our digression would be longer than necessary and outside our limits were we to show the epistemology of the

12 For this comparison vid. Nys, 431.
13 Hoenen, 452, tr. by author of thesis.

Euclidean and non-Euclidean geometries. Suffice it to say that the validity of one geometry qua geometry does not destroy the validity of the others. It is only on the point of the application of some particular geometry to our world or universe that argument occurs. To say that our world is approximately Euclidean means that geometrical figures constructed out of practically rigid bodies and measured by a practically rigid rod have approximately the properties expressed by the propositions of Euclidean geometry.[14] Now, it was the effort to measure these approximations that has given rise to the theory of relativity.[15]

In entering now upon the question of curved space, as Eddington describes it, I believe that it is unsound for a philosopher to have an initial prejudice such as Father Brunner voices when he says, "No curved space exists because no space at all exists."[16] It is precisely against this attitude that this thesis is written. The author feels that it is a lack of understanding of the scientists' terminology that breeds part of the misunderstanding between Scholastic cosmologists and the scientists. How different, indeed, if we find that the scientists say that "curved space" means "a space having Riemannian measures of curvature,"[17] or "essentially a mathematical con-

14 Lenzen, V.F., The Nature of Physical Theory, John Wiley, New York, 1931, 63. Also cf. Maritain, Jacques, Les Degres du Savoir, Desclee de Brouwer et Cie., Paris, 1932, 324.

15 McWilliams, S.J., J.A., Cosmology, The Macmillan Company, New York, 1938, 123.

16 Brunner, S.J., August, Fundamental Questions of Philosophy, tr. by Sidney Raemers, Herder, St. Louis, 1937, 175.

17 Webster's Unabridged Dictionary: "space, curved."

cept, the formulae of which have meaning only for the trained mathematician,"[18] or that

> the gravitational field is therefore identical with the structure of space ...and space is warped under the influence of the sun's mass and leaves no other path free for the planet than the curved one.[19]

For Eddington's concept of curved space I am choosing one excerpt from The Nature of the Physical World which will summarizes the idea and serves as a basis for our subsequent philosophical analysis. Note the references to the non-Euclidean Riemannian measures of curvature.

> Some of you may feel that you could never bring your minds to conceive a curvature of space, let alone of space-time; others may feel that, being familiar with the bending of a two-dimensional surface, there is no insuperable difficulty in imagining something similar for two or three or even four dimensions. I rather think that the former have the best of it, for at least they escape being misled by their preconceptions. I have spoken of a "picture," but it is a picture that has to be described analytically rather than conceived vividly. Our ordinary conception of curvature is derived from surfaces, i.e., two-dimensional mani-

18 Draper, Arthur L., and Lockwood, Marian, The Story of Astronomy, Dial Press, New York, 1939, 371 -- commenting on the Einsteinian universe. Note that it is the formulae that these authors hold are wholly unintelligible to the layman -- not necessarily all the concepts.

19 Reichenbach, Hans, Atom and Cosmos, tr. by E.S. Allen, New York, The Macmillan Company, 1933, 83.

> folds embedded in a three-dimensional space. The absolute curvature at any point is measured by a single quantity called the radius of spherical curvature. But space-time is a four-dimensional manifold embedded in -- well, as many dimensions as it can find new ways to twist about in. Actually a four-dimensional manifold is amazingly ingenious in discovering new kinds of contortion, and its invention has not been exhausted until it is provided with six extra dimensions, making ten dimensions in all. Moreover, twenty distinct measures are required at each point to specify the particular sort and amount of twistiness there. These measures are called coefficients of curvature. Ten of the coefficients stand out more prominently than the other ten. Einstein's law of gravitation asserts that the ten principal coefficients of curvature are zero in empty space. If there were no curvature, i.e., if all the coefficients were zero, there would be no gravitation.[20]

To summarize these views of curved space, it would appear that

a) this space is equivalent to extension;

b) it is inside the universe;

c) in itself it is not a material thing, but the properties that belong to the bodies in that space are ascribed to it instead as if it were a real being;

d) it must be understood as a mathematical concept, not imagined as from experience, since it refers to higher mathematical determinations of a body in motion;

e) it is taken merely quantitatively, not from any

20 The Nature of the Physical World, 119.

other aspect;

f) we now approach perilously close to "not so much the thing measured as the measurement."[21]

We shall consider curved space again in the next chapter, but for the present let us note once more that we do not intend to criticize the entire theory of relativity from a philosophical viewpoint; our sole task will be ultimately to compare notes of Eddington's space-concept with the Scholastic doctrine. For the present we are merely compiling these notes.

A striking statement respecting curved space occurs in the other connection previously mentioned: what of space beyond the universe? Here we are discussing something very closely related to the Scholastic concept, yet Eddington deliberately shies from making a scientific decision.

> Is there an end to space? If space comes to an end, what is beyond this end? On the other hand the idea that there is no end, but space beyond space is inconceivable. Prior to the relativity theory the orthodox ~~theory~~ view was that space was infinite. No one can conceive infinite space. We had to be content to admit in the physical world an inconceivable conception....Infinite space cannot be conceived by anybody; finite but unbounded space is difficult to conceive, but not impossible.[22]
>
> As has already been explained, the modern view is that space is finite -- finite though unbounded.[23]

21 Sheen, 25.
22 The Nature of the Physical World, 80.
23 Ibid., 166.

Generally in the literature on this subject the comparison is given of the surface of a sphere -- finite though unbounded -- to illustrate the same possibility for space.

Eddington in the above statements adds more to his concept. Space is inside the universe; it is not to be treated as the absolutely universal receptacle. He retains the idea of extension consistently. "Finite but unbounded extension" would now give the "picture" of a spherical universe where the laws of non-Euclidean Riemannian geometry hold. The logically consequent questions whether this geometry actually does apply or can be applied to our universe and whether Eddington seems to imply that the possibility of mental conception of a type of space would regulate its reality, must be ruled out like the other questions we have encountered that are outside the scope of this thesis.

Finally, before summarizing Professor Eddington's views as we have obtained them from The Nature of the Physical World, let us note one last assertion that has direct reference to the space-time concept of Eddington and the relativists.

> We know nothing about the intrinsic nature of space, and so it is quite easy to conceive it satisfactorily. We have intimate acquaintance with the nature of time, and so it baffles our comprehension.[24]

24 Ibid., 51.

Starting with these principles (the question of whose accuracy we must transmit for the moment) Eddington proceeds to unite our three dimensions of space with the fourth, time, into the "space-time continuum" in which every event is placed, according to the theory of relativity. The detailed consideration of space-time must be considered with the many related items we have been encountering as outside the limits of our investigation; for when Eddington speaks of "space" separately, it is part of our subject, but with the incorporation of the space-time concept we are in a totally different field. "Space and time as separate entities have disappeared from the universe,"[25] and we find ourselves on the verge of Samuel Alexander's space-time philosophy, the matrix out of which everything is evolved;[26] or in the company of certain relativist writers who in speaking of the space-time concept seem to identify time with space as a univocal term.[27]

In conclusion, let us set down by way of summary the following points describing Eddington's concept of space as he has revealed it in The Nature of the Physical World:

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25 Jeans, Sir James, The Mysterious Universe, The Macmillan Company, New York, 1932, 13.

26 Cf. Bittle, 383.

27 Swann appears to be a typical example of this group. His Architecture of the Universe is a very apodictical work making space-time the explanation and the goal of the universe, incidentally thus explaining away the existence of a personal God via the Great All-- Space-Time! Cf. Swann, W.F.G., The Architecture of the Universe, The Macmillan Company, New York, 1934, passim.

a) For Eddington, all space that can be considered must be inside the universe; space outside the universe is inconceivable.

b) The wider sense of the word predicates relative, not absolute, emptiness of all space inside our universe.

c) Mathematical space is always equivalent to extension; consequently it is always measurable.

d) It acts as a point of reference, a "frame," giving bodies their location.

e) The properties ascribed to it actually belong to the bodies in it.

f) These properties are strictly quantitative, being mathematical determinations flowing from certain equations and formulae.

g) Eddington does not assert that time is a univocal fourth dimension, as is supposed sometimes.

h) Eddington's space is finite though unbounded.

i) His concept of curved space involves many mathematical "dimensions" beyond those of our common experience. The meaning of the mathematical dimension is only analogically, not univocally, that of the dimensions of length, width, and depth that we experience.

CHAPTER IV.

EDDINGTON'S SPATIAL CONCEPT AS DESCRIBED IN HIS OTHER BOOKS

Earlier in this thesis it was stated that we would not consult Eddington's philosophical system but rather his terminology in its scientific usage. Now, it is true that The Philosophy of Physical Science is more a philosophical than a scientific treatise, yet in several passages that later introduce philosophical concepts, Eddington describes space from a scientific viewpoint we have not yet met. Consequently, we will transcribe some of these passages here. He is engaged in expounding the nature of structural concepts, and as a typical example contrasts the structural concept of space with its general concept.

> In order to formulate this point explicitly we shall distinguish between a structural concept and more general kinds of concepts. A structural concept is obtained from a corresponding general concept by eliminating everything which is not essential to the part it plays in a group-structure.[1]

This structural concept, he adds, is an element in a pattern, whose only properties are its connection with the pattern. Its properties are those of a mathematical symbol which has no mean-

1 Eddington, A.S., The Philosophy of Physical Science, The Macmillan Company, New York, 1939, 144.

ing in itself but "consists solely of its association with other symbols." If a general concept exists that corresponds to this structural concept (the symbol), the general concept is our idea of what the structural represents in our non-mathematical form of thought. It lacks the precision of mathematics.

> Except as applied to sensations, emotions, etc., of which we can be directly aware, it is doubtful if the general concept is more than a self-deception which persuades us that we can have an apprehension of something we cannot apprehend.[2]

For the present let us transmit the accuracy of this statement, remembering, however, to apply it to Eddington's structural and general concepts of space when he calls them such.

> To show how these ideas are applied let us consider the concept of space. Taking first the general concept, we usually regard Euclidean space as the simplest kind of space to conceive. One would have thought that the infinitude would be rather a serious obstacle to conception; but most people manage to persuade themselves that they have overcome the difficulty, and even profess themselves utterly unable to conceive a space without infinitude.[3]

The common concept of Euclidean space, then, as the indefinitely large receptacle is "a self-deception which persuades us we can have an apprehension of something we cannot apprehend"? If we were to think of infinity solely as indefinite extension in terms of an equation, then we would be in extremely deep mathematical waters, for according to Professor Eddington "the structural

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2 Ibid., 144.
3 Ibid., 145.

concept of Euclidean space is exceptionally difficult. . . . It requires more advanced mathematical conceptions to formulate the specification."[4] However, if we obtained this concept of infinitude by abstracting from sense-perceptions, must we call ourselves self-deceived just because Professor Eddington cannot formulate our concept in terms of a mathematical equation? I hardly think so -- but a further criticism of this view must await the summary in the final chapter.

Uniform spherical space, Eddington hastens to add, offers a comparatively easy illustration of a structural concept.

> Any point in spherical space can be changed into any other point by a rotation of the sphere. Thus, to the points or elements of spherical space A, B, C,.....,there correspond operators P, Q, R,.....,which are the rotations of the sphere; and the group of the operators is simply the group of rotations in the proper number of dimensions. Regarding "space" as a structural concept, all that we know about spherical space is that it has the group-structure of this group of rotations.[5]

Here, then, is another statement to show that Eddington makes his mathematical equation his sole criterion, and that when he says "space has certain properties," he means, "bodies moving in space have certain properties according to such and such an equation." For him the structural concept of space must come through an equation; without an equation it is a meaningless

4 Ibid., 144-5.
5 Ibid., 145.

symbol. But since the structural concept is alone "precise" and "unembellished," the mathematical equation of space alone is correct. And in Eddington's final reference to this "inaccurate and therefore incorrect" general concept of space, he states that space as it appears in familiar apprehension -- what it looks like, what it feels like, its negativeness as compared with matter, its "thereness" -- all this is an embellishment of the bare structural description. This embellishment, moreover, is an unauthorized addition to physical knowledge, which we are fortunately discouraged from making by our difficulty in conceiving the space of modern physics non-mathematically.[6]

Summarizing these views from The Philosophy of Physical Science without yet passing judgment on them, we can safely state that Professor Eddington advances the following doctrine: Except for the data of immediate perception, when we have a non-mathematical concept, we do not have precise or correct apprehension; a mathematical concept, obtainable only by way of a mathematical equation, is needed for that precise and correct apprehension; and the case of space is a typical one. As a consequence, space can be apprehended not as a "deception" but with "precision" when it is expressed as a mathematical equation, and even then never by itself but as a mathematical symbol getting its meaning from its association with other symbols.

6 Ibid., 146.

Another Eddington book, New Pathways in Science, is partly a review of material given in The Nature of the Physical World and elsewhere, and partly a first publication of new work done in the field. We can conveniently divide the excerpts we are to appraise into three general groups: first, related quotations confirming selections made in the previous chapter; second those relating to the distinction between space and time; and third, those relating to spherical or curved space.

One point on which every Scholastic cosmologist can heartily congratulate Professor Eddington is his rejection of the absolutely-empty (scientific) space and his equally doughty championship of the existence of the aether.

> Some distinguished physicists maintain that modern theories no longer require an aether -- that the aether has been abolished. I think all they mean is that since we can never have to do with space and aether separately, we can make one word serve for both; and the word they prefer is "space." [7]

They fear, says Sir Arthur, that the word aether might convey the idea of something material; but equally, he rejoins, the word space is liable to convey the idea of complete negation. Moreover, they employ an army of mathematical symbols to describe conditions at any point. For some, the word "space" conveys the idea of passive emptiness, characterless void; this is a connotation far inferior to that possessed by the aether when

7 Eddington, A.S., New Pathways in Science, The Macmillan Company, New York, 1933, 39.

it is conceived even as a sort of material jelly.

> But it is possible to compromise by using the term field. The field includes both an electromagnetic field and a gravitational or metric field; and the army of symbols to which I have alluded describes the two fields. Space (in its ordinayy physical meaning) is the same thing as the metrical field; for the symbols describing the metrical field specify the one characteristic that we are accustomed to ascribe to a space, viz., its geometry (Euclidean or non-Euclidean).[8]

Immediately after a fine defense, Professor Eddington becomes an adversary of the Scholastic cosmologist. And that is occasioned simply by this statement that in physics space is equivalent to pure mathematical space and is described mathematically according to the one characteristic it possesses, its geometry. Here again we find Eddington making quantitative measurements the be-all and end-all of his science. Mathematical extension alone, being quantitative abstraction, cannot tell everything about a physical body. Furthermore, it is exactly in the vital question of the specification and application of a particular geometry to space, or rather to the bodies in that space, that Eddington must meet opposition.

There is one particularly incisive assertion yet to be noted repudiating the notion of empty space, and since there is so much on which we have to disagree with Professor Eddington, we ought perhaps to help the balance with this distinction

8 Ibid., 40

between space in one of its many meanings, and vacua.

> You cannot have space without things, or things without space; and the adoption of thingless space (vacuum). . . is a definite hindrance to the progress of physics. By this self-contradictory and irrelevant conception we have . . . made an abstract separation of the theory of space (field) from the theory of things (matter).[9]

Another point on which Professor Eddington should be quoted favorably is his clear distinction between the meanings of space and time as "dimensions." This may seem at first sight a belaboring of the very obvious, but there exists a misconception that relativists (among whom Eddington might be counted) talk gibberish about four univocal dimensions, three of which are spatial, and the fourth, temporal, but yet considered the same as the spatial trio. Moreover, certain relativists[10] have evolved a philosophical or "theological" system that virtually apotheosizes the concept of space-time. Such extensions of the mathematico-physical theory add to the confusion. Hence, we quote Eddington's distinctions.

> There is no bending around of time to bring us back to the moment we set out from. In mathematics we find it convenient to provide for this difference between the closed character of space and the open character of time by the means of the symbol $\sqrt{-1}$.[11]

9 Ibid., 48.
10 Alexander; Swann, passim; vid. Bittle, 455.
11 New Pathways in Science, 51.

And after a set of mathematical operations:

> Thus the distinction between space and time is already foretold in the structure of the set of E-operators. Space can have only three dimensions because no more than three operators fulfill the necessary relationship of perpendicular displacement. A fourth displacement can be added, but it has a character essentially different from a space displacement.[12]

And now, having shown from his own words that Professor Eddington's concept of space is essentially different from that of time, even in his most advanced theorizing, we come to treat in detail of his views on "curved space" -- the notion of three dimensions "bent," and ultimately to be related to a fourth dimension, time. We have already touched on this subject in quotations in the previous chapter, but the explanation was left for the present section. Without doubt the evaluation of these views on curved space constitutes the most difficult task hitherto attempted in this thesis. We shall summarize Eddington's statements as he converts "curved space" from a purely mathematical equation into a concept explained in words. But where and how can we obtain Eddington's correct views on this topic? His purely mathematical treatises are ruled out at once; and in the popularizations that remain, some pages are devoted to the consideration of curved space in each of them. I am choosing The Expanding Universe as our chief source, since its exposition is the most detailed of any I have seen in

12 Ibid., 276.

Eddington's popularizations. Its entire second chapter, "Spherical Space," is too long for literal transcription here, and parts of it are irrelevant in this thesis. Accordingly, I shall give the gist of the description, using Eddington's terminology throughout.

The physicist, says Sir Arthur, is suspected of talking metaphysically when he refers to curvature of space, yet space is a prominent feature of the physical world; and if the physicist has found surprising ultimate or semi-ultimate facts about the world which crude sensory perception could not reveal, why should there be surprise when this physicist finds a new and surprising property of space? Space-curvature is a purely physical characteristic discovered by suitable experiments and measurements.

> The nomenclature is that of the pure geometers who had already imagined and described spaces with these characteristics before their actual physical occurrence was suspected.[13]

"Curvature of space" is a technical term with a specialized meaning in science. We may conveniently describe the property by the imaginary operation of bending or curving which would remove the flatness of space if it could be performed. In order to use this mode of description a fictitious dimension is introduced which would make the operation possible. Bending a flat two-dimensional surface brings in the third dimension; likewise,

13 Eddington, A.S., The Expanding Universe, The Macmillan Company, New York, 42.

bending a three-dimensional space adds and postulates a fourth fictitious dimension.

But only in simple and symmetrical conditions does this fourth dimension suffice; the general picture requires ten dimensions when we extend the same idea from space to space-time. How to conceive these added dimensions? Just as we picture a magnetic field. Space-curvature is something found in nature that is recognizable by certain tests for which ordinarily we need not a picture but a name. Yet despite such a disparagement as this of picturization of our three-dimensional space contorted in fictitious dimensions, there is one application where the picture is helpful and non-misleading. This is the curvature of bent space which may be sufficient to give a "closed" space in which it is impossible to go on indefinitely getting farther and farther from the starting point -- just as the surface of a sphere differs from a plane infinite surface. Thus the three-dimensional space bends so far as to be (1) curved and (2) closed. Here in our solar system the curvature is small and amounts to only a slight wrinkling. With the irregularities introduced by the galaxies and all masses of matter, the entire universe may be roughly shaped like a pear or sausage --perhaps. And in this spherical space, as on our world, a traveler departing on one "straight" line would eventually return to his point of origin. Finite but unbounded, there is no point of entrance or exit to this closed space. The existence of spherical space

is postulated by the phenomenon of the ever-expanding universe, which is in turn borne out by irrefutable astronomical evidence,[14] while on the other hand the assumption of flat physical space leads to very serious logical difficulties and precludes the existence of the type of galaxy contemplated in Einstein's and Lemaitre's theory of the universe.[15] It is not a case of supposing that the space is already there into which our universe is to be expanded; the space expands with the universe as if the galaxies were imbedded in the walls of an ever-expanding balloon. Curved space is a measurable constituent of the physical universe.

This summary of Eddington's description of curved space can well be rounded out by the following parallel passages in New Pathways in Science:

> The world is closed in its three space-dimensions, but it is open at both ends in its one time-dimension.[16]

We shall evaluate curved space in the final chapter.

In Eddington's two books devoted to astronomy, Stars and Atoms, and Internal Constitution of the Stars, there is little said about this curvature of space in the distant corners of the universe. The reason seems to be that the question of curvature of space belongs to a section of astrophysics that is more theoretical than that described in these two somewhat -

14 This material is given in The Expanding Universe, 41-53.
15 Ibid., 59.
16 New Pathways in Science, 51.

technical books on the nature of the stars. The excerpts here given are instances representing the meaning of space in its very infrequent use in these two books.

> Betelgeuse has a density about a thousandth that of air. We should call it a vacuum were it not contrasted with the much greater vacuosity of surrounding space.[17]

> The system of stars is floating in an ocean -- not merely an ocean of space, not merely an ocean of aether, but an ocean that is so far material that one atom or thereabouts occurs in each cubic inch.[18]

> This is the "fulness" of interstellar space already mentioned.[19]

> Interstellar space is at the same time excessively cold and decidedly hot.[20]

Thus, space is used throughout in the ordinary sense -- it denotes the relative emptiness that exists between stars. Then, too, it is virtually equivalent to the extension in which stellar bodies exist and in which their relative distances can be measured. Curved space is out of the discussion here since the subject turns to a less mathematical side of astronomy.

By way of concluding our exposition of the properties of Eddington's spatial concept, I should like to give several excerpts from the earliest of Eddington's popularizations, Space

17 Eddington, A.S., Stars and Atoms, Yale University Press, New Haven, 1927, 64.
18 Ibid., 67.
19 Ibid., 66.
20 Ibid., 69.

Time, and Gravitation -- the one book remaining to be considered. It is to be noted that despite the title, this book does not refer directly to our topic except in two of its thirteen chapters, and that it offers both a more mathematical treatment and a more technical exposition than any of the popularizations that follow it. Eddington does not set forth any new properties of space in it, and what he does say has been more clearly described in The Nature of the Physical World. Consequently, I am merely citing certain passages that confirm our analysis of the elements of Eddington's concept of space.

Space does not denote merely emptiness or nothingness, but rather the idea of measurability. In itself it approaches objective reality -- it seems to exist almost as an independent being, if we judge from the wording of certain passages below. The pertinent words are underlined.

> I was speaking of a proposition of geometry -- properties of space, not of matter.... What we may call the field of extension, or space-field is just as much a physical quality as the magnetic field. As to how far apace really resembles a magnetic field, I do not wish to dogmatize; my point is that they present themselves to experimental investigation in very much the same way.[21]
>
> You imagine the intervals filled with uniform space; but the uniformity simply means that the same amount of

21 Eddington, A. S., Space, Time, and Gravitation, Cambridge University Press, 1920, 3.

> space corresponds to each inch of your rigid measuring-rod.[22]
>
> I have no knowledge of space apart from my measures.[23]

Curved space, as in The Expanding Universe, means that "the extensional relations of matter obey somewhat modified laws."[23a] "It is not contrary to reason, but contrary to common experience, which is a very different thing since experience is very limited."[24] Eddington thus holds that the workings of the universe are explained by something we do not perceive in everyday experience. It is particularly interesting to us to note in the above quotations the connection he makes between matter itself and the behavior of matter in curved space.

On the subject of the impossibility of absolutely empty space, Sir Arthur holds the same common-sense view as in his later works. Aether must exist.

> Physicists and philosophers have long agreed that motion through absolute space can have no meaning; but in physics the question is whether motion through aether has any meaning.[25]

Finally, one concluding paragraph of Sir Arthur's gives us his explicit description of what space means to him. This is a most apt excerpt (and is, as well, most fair to its author) because it affords us a true summary of the properties

22 Ibid., 5.
23 Ibid., 7.
23a Ibid., 8.
24 Ibid., 91.
25 Ibid., 15.

of Eddington's spatial concept as we have been attempting to compile them.

> We have been trying to give a precise meaning to the term space so that we may be able to determine exactly the properties of the space we live in. There is no means of determining the properties of our space merely by a priori reasoning because there are many possible kinds of space to choose from, no one of which can be considered more likely than any other. For more than 2000 years we have believed in a Euclidean space because certain experiments have favored it; but there is now reason to believe that these same experiments when pushed to greater accuracy decide in favor of a slightly different space (in the neighborhood of massive bodies).... When the relativist speaks of space, he means the space revealed by measurements, whatever its geometry. He points out that this is the space with which physics is concerned.... The relativist in defining space as measured space clearly recognizes that all measurement involves the use of material apparatus; the resulting geometry is specifically a study of the extensional relations of matter.... Since...space-order cannot be discussed without reference to time-order as well, it has become necessary to extend our geometry to four dimensions in order to include them.[26]

For Eddington, accordingly, Riemannian geometry is the sole and entire explanation of the universe. This fact is postulated because scientific astronomical measurements apply best to a universe in which the space of this non-Euclidean geometry holds sway. Is this space a real thing? Eddington

26 Ibid., 16.

constantly seems to attribute some degree of existence to it as a real being since it is something primarily and solely measurable; but on the other hand in his phrase, "space is the extensional relations of matter," and "Euclidean space," he appears to be considering the conformity of moving bodies to certain geometrical laws. In other words, he describes the behavior of matter under certain conditions. To remove this vagueness we ourselves would have to interpret Eddington's statements to make them hold definitely for or against the existence of space as a real being -- and in this we could very easily fall into the apparent or actual error of arriving at a meaning the scientist did not intend. For this reason, we must state our analysis, as it is now to follow in Chapter V, in terms of "seem" and "appear."

CHAPTER V.

A COMPARISON OF THE SPATIAL CONCEPT OF EDDINGTON AND THE SCHOLASTICS

In explaining the nature of space in Chapter II, we stated that physical space was the concept being defined, and that pure mathematical space was not included in our discussion. The objection might now be raised, how can we draw a comparison between Eddington's concept of space and the physical space of the Scholastics? Inasmuch as Professor Eddington appears to treat everything from the mathematical standpoint, should not his space be called mathematical space, and like it be omitted from discussion in a comparison like the present one that is built around the Scholastic thesis?

The answer to this difficulty is that Eddington's space cannot be called pure mathematical space simply because he founds his concept on quantitative experiments. Sir Arthur studies the physical world as it is revealed by scientific research and as it actually exists around us; hence, everything he discusses as a scientist -- space included -- must be placed outside the realm of theoretical mathematics and classed in the physical order.

For the Scholastics, as was said previously, physical space is a conceptual being founded in reality. It embraces real and possible space, is the universal receptacle, is immaterial, permeable, infinite, eternal, uncreated, indestructible, immeasurable, incompressible, and undilatable. Eddington's space on the other hand appears on first sight to have its existence and reality more outside the mind than in it, since all its properties have ostensibly been determined as part of a theory explanatory of the results of direct physical experiment. Yet, its foundation is not in the actual physical world but in the Riemannian geometry which, Eddington holds, is the most promising explanation we can find to the riddle of the universe, and which wholly holds true when applied to the universe as revealed to us by the physical sciences.[1] Thus, Eddington's space ultimately exists more in the mind than out of it by reason of this close connection with and dependence on a pure geometry. Such a type of existence is in accord with the idealistic philosophy Sir Arthur professes.

The space he describes is always inside our universe. He could almost say that it <u>is</u> our universe.[2] He is very explicit that the determination of what lies outside the universe has not fallen within the confines of astronomy or physics. Particularly in his rejection of the Euclidean notion that

1 References in this chapter are to a previous chapter and page number. In this instance, III, 22.
2 E.g., III,25; III, 27.

space is infinite and stretches indefinitely in all three dimensions does this point appear. Hence, it seems quite apparent that the Scholastic concept is more comprehensive, is broader, than Eddington's, for the former refers to space both inside and outside the universe, space that is infinite and unbounded. Eddington's "finite but unbounded space" still rides on the sea of the infinite imaginary space that bounds it.

Closely approaching the fact that Eddington's space is uniformly considered to be inside the universe is the fact that it is exclusively coexistent with the universe. This means that it is not eternal, but began with creation when the evolutionary universe (according to Eddington and modern scientists to a great degree) came into existence.[3] Moreover, this existence of the universe is something dynamic, for the universe is constantly expanding not into space but rather with space. Logically, then, in view of the interdependence of matter and the curvature of space, when all matter in the universe will be destroyed, space will be destroyed with it. We can note here several clear divergencies between the spatial concepts we are comparing. While space is not eternal, indestructible, incompressible, nor undilatable for Sir Arthur, for the Scholastics the opposite holds true in each case.

Professor Eddington endows space with one great

3 E.g., III, 27.

quality, measurability or extension[4]; and yet, as was said above, we cannot make this extension equivalent to pure mathematical space inasmuch as Sir Arthur likewise asserts that this "metrical field" -- already in the second degree of abstraction where only quantity remains -- is the sum and substance of the reality existing in our universe in which no abstraction exists as such. His space consequently amounts to a mathematical explanation of the workings of the universe. Now, it is true that physical science may abstract from individuality and may explain our world in terms of classes and groups, but it may not then proceed to abstract from all notes of real things except their quantity and assert that this quantitative explanation is both the ultimate and entire explanation. The physical content or nature of space in the universe can be only partially explained by mathematical analysis. For an entire explanation science must consider the qualities that cannot be classed under quantity; for an ultimate explanation it must yield the field to metaphysics, which will analyze all reality in terms of being.[5]

In calling space a metrical field[6] Eddington approaches if anything, the problem of place and "whereness" (ubication) but his solution must necessarily be less ultimate than the Scholastic explanation by reason of his system of placing an object in space and time solely according to quantity. We

4 E.g., III, 33, 34
5 This is a point fully developed in Sheen.
6 III,19; IV,32,33; IV,43.

must not forget that it is part of the relativity theory which he expounds, to have a "frame of reference" both for distance and for time. Space is made to act as one of these frames. Eddington calls for a space in reality that will have all the properties of pure geometrical space. Its "intrinsic magnitude" (the property of being a metrical field) must make it the background for the absolute measuring-stick, and according to his theory nothing except light is a reliable norm for that purpose. Eddington's space accordingly becomes a "locans particulare" -- a thing that gives location to particular objects in the universe. In no way can it be thought of as the physical space of the Scholastics, which is conceived as the "locans universale," even though this physical space cannot do the "locating" mathematically since in itself it is not an objectively real being. Physical space is said to locate the universe because it is thought of as encompassing the universe; but Eddington's space does not encompass the universe and consequently cannot "locate" it.

Another point noticeable in the writings of Eddington (and of other relativists as well) is the attribution of certain qualities to space when in reality the writer attributes these qualities to the bodies in that space. Eddington makes clear that his space is not something material. His defense of the aether as the substratum of the physical universe shows his opinion plainly. Moreover, on this point he is as consistent

as he is definite, and that in all his books. How, then, can he ascribe properties to space (the non-material being), properties which can belong only to material beings?[7] Curved space is truly a mathematical concept at best, expressed in a mathematical equation and not picturable, he says; but straightway it is supposed to be pictured in order that its closed character can be understood. Or again, he states that there is no such thing as a straight line in the Einstein-Riemann universe, that space becomes more curved the more mass it contains, and that the greater the mass, the greater the curvature, or in other words, the gravitational attraction. A ray of light leaving its source can conceivably return to this source from the opposite direction after having traversed the spherical universe. How, then, can he call this space "curved and closed" when what he really seems to mean is that the path of a ray of light describes an immense orbit and is influenced in its curvature by the mass it passes? From our summary of Eddington's explanation of curved space, it will be remembered that he uses the example of a traveler moving in a "straight" line through curved space, and all the properties ascribed to the space become those of the traveler. That "curved space" is merely a modus loquendi of the mathematician, a sort of conceptual being (ens rationis) used to express judgments respecting the mathematical behavior of bodies in that space, is a suspicion con-

7 E.g., III,25; IV,38,39; IV, 43.

firmed by passages in the writings of other physicists of Eddington's school of thought.[8] In such passages the properties of space are explicitly referred to bodies in it and to the paths they follow.

Are the "dimensions" of Eddington's space used in the ordinary and Scholastic sense? When he speaks of the three dimensions even in his curved space, Sir Arthur appears to use the ordinary meaning of length, width, and depth, except for the impossibility for the three dimensions to extend as straight lines over immense distances. However, when he treats of time as a fourth dimension, or of the six added "dimensions" in the space-time manifold, he is using a decidedly technical mathematical meaning. "Dimension" now signifies a mathematical determination or quantity in an equation having to do with geometry--nothing more.

One point remains on which there is a shapp difference of opinion between Eddington and the Scholastics. It will be remembered that Eddington uses a "structural concept" of space throughout, in distinction to the "general concept."[9] The structural concept is built up not according to what it means in itself, but according to what it means in association with other associated symbols, as in a mathematical equation. Because it is mathematical, the structural concept is therefore precise

8 Cf. Group "B" of the Bibliography; also vid. III,25, n. 19.
9 IV, 31, 32.

and accurate. On the contrary, the general concept is supposed to be our apprehension of a non-apprehensible (i.e.,a purely mathematical thing?) object. It is not precise, it is an embellishment which adds inaccuracies to a clean-cut mathematical concept. According to Eddington's clear statement (quoted at the beginning of Chapter IV), the apprehension of anything non-mathematical is vague and is something of a self-deception, with the exception of our immediate perception of states of consciousness. All this means for Sir Arthur that the Scholastic concept of space would be "vague and a self-deception" because it was not obtained from a mathematical equation nor could it be expressed as such. This we must positively deny. Physical space is a "conceptual being founded in reality," and with the notes it possesses is not a pure chimera of the fantasy, but is a valid concept formed by putting together separate notes abstracted from various ideas of daily experience with extended bodies. That it cannot be imagined correctly nor formulated as a mathematical symbol in an equation but that it must be understood as a concept -- this is no argument against its accuracy or its ontological truth.

The following tabulated comparison gives a brief summary of the points brought forward in the body of this thesis and analyzed in the course of this chapter.

SCHOLASTIC SPACE	EDDINGTON'S SPACE
Conceptual being with a foundation in reality.	A mathematical entity applied as an explanation of the workings of the universe.
Both inside and outside the universe, i.e., both real and possible.	Solely inside the universe, i.e., real.
Contains and permeates the universe.	Permeates the universe.
Immaterial.	Immaterial.
Infinite	Finite.
Unbounded	Unbounded according to Eddington, but actually bounded by possible space.
Eternal, uncreated, indestructible.	Coexistent with the universe.
Immeasurable.	Primarily measurable.
Incompressible and undilatable.	Expanding with the expansion of matter in the universe.
"Locans universale."	"Locans particulare."
Locates bodies.	Locates events together with time.
All notes can be imagined separately and abstracted from real beings in everyday experience.	To be understood as a mathematical concept; cannot be imagined properly in terms of everyday experience.
Its quantitative notes have the properties of Euclidean geometry.	Possesses solely the qualities or properties of Riemannian non-Euclidean geometry.
In itself it is absolute nothingness and emptiness and is used to signify relative nothingness.	It is used as indicating relative emptiness only in the loose sense; in the strict sense it is a background for measurement.

This brings to a close our examination of Professor Eddington's concept of space and our comparison of it with the physical space of the Scholastics. There remains a final question to be answered, namely, what benefit results from this investigation, and to what conclusions does it lead?

Primarily, this fact stands out: Professor Eddington attaches a very different meaning to the word "space" than do Scholastic cosmologists. Concerning some properties of his concept (e.g., immateriality) there can be full agreement; a second set of notes which he attributes to space (e.g., the exclusive accuracy of the structural concept of space) the Scholastics can only deny and refute. Concerning the third and remaining group of properties, which is by far the largest, the Scholastics and Professor Eddington can neither agree nor disagree, for this third group belongs wholly to the realm of science or theoretical mathematics. They neither affirm nor deny the notes of the Scholastic spatial concept. Philosophers as philosophers cannot pass judgment on these purely scientific claims. It is only when Professor Eddington or some other scientist attempts to trespass upon the domain of philosophy by claiming that physical science alone or mathematics alone is the explanation of the ultimate, that there could be argument concerning these scientific claims or facts of the third group. Under such a hypothesis these purely scientific data would lose the value they possess in their own field when subjected to an

attempt to make them hold true in a superior field, philosophy. For example, the fact that Eddington's space exists solely inside the universe could not be used validly as an argument against the Scholastics who hold that space cannot exist anywhere as an objectively real being.

Thus, this thesis leads up to its goal, the comparison of the spatial concept of Eddington and the Scholastics. Incidentally, the fact has been established that on points where Scholastic cosmologists are to analyze scientific claims, there must be a mutual understanding of the terminology used on both sides before judgment is to be passed. Whether or not the scientific phenomena have been correctly observed must, of course, be determined by the scientists; whether or not a scientific theory (such as the relativity or quantum theories) is scientifically correct, likewise belongs to the scientists to determine. But once the question of ultimate interpretation arises, the philosopher must come on the scene. He may not straightway reject the possibility of curved space or of ten dimensions or similar scientific claims because the concepts at first sight appear absurd or contradictory; he may find as we have found that technical usage sometimes alters the meaning of common words profoundly, and that he cannot apply his philosophical principles until he has applied a common denominator to his scientific and philosophical terminology.

With regard to Professor Eddington we have tried to follow precisely this course. It was not for us to judge his scientific accuracy or even to pass on the philosophical stability of his scientific interpretations; but we have attempted to show that with proper understanding of his wording, some of the statements of Eddington the scientist do, and some do not, make him an opponent of Scholasticism on the question of what constitutes space. Most of them do not do so, for they refer to a concept identical in name but different in content from that of absolute space as understood by the Scholastics.

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