Black Listed: An Outlines of Theory of Relativity

In Honor To Sir Arthur S. Eddington, who first prove the bending of light rays due to mass and gravity thus, conforming one of the predictions of Theory of Relativity, and author is not updated about it's state and trend in researches.

Note:

Since Sir A.S. Eddington, verified one of the predictions of Relativity, author thought to researches in experimental practices. read Eddington's book itself, as it would provide the views of the person, who did such an tremendous work, though other authors too have provided their deep insights and understanding of Relativity.

But author guesses, it was Sir A.S. Eddington, who paved the way for further research more rigorous

GTR.

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- The use of space-time co-ordinates was based only on the basis of the laws of constancy of the velocity of light.

- From GTR the velocity of light must always depend on the use of co-ordinates whenever a gravitational field is present.

- The presence of gravitational field invalidates the definition of the co-ordinates and time which creates objection in STR.

- The Gaussian co-ordinate system are essentially equivalent for the formulation of the general laws of nature.

- In gravitational fields, there are no such things as rigid bodies with Euclidean properties. Thus, the fictitious rigid body of reference is of no avail in the GTR.

- The space-time distribution of this/these gravitational field is of the kind that would not be possible on Newton theory of gravitation.

- From GTR, the velocity of light must always depend on the co-ordinates when a gravitational field is present. We found that the presence of a gravitational field invalidates the definition of the co-ordinates and time which leads us to the objective in the STR.

Space Time and Gravitation

preface

→ Einstein has succeeded in seperating far more completely than hitherto the share of observer and the share of external nature in the things we see happen. The perception of an object by an observer depends on his situation and circumstances: for example distance will make it appear smaller and dimmer.

→ Allowance made for the motion of observer hitherto been too crude a fact overlooked because in practice all observer share nearly the same motion, that of the earth.

→ When space and time are relegated to their proper source the observer, the world of nature which remains appears strangely unfamiliar; but it is in reality simplified, and the underlying unity of the principal phenomena is now clearly revealed.

→ The new view of space and time, so opposed to our habits of thought, must in any case demand unusual mental exercise.

→ There is a relativity of truth, as there is relativity of space.

→ In the geometry of relativity in its perfect harmony experiences a truth of form and type in nature, which any knowledgeable version misses

→ And demands that it shall be alloyed with familiar image

Prologue

→ Any two sides of a triangle are together greater than the third side.

→ I can deduce it by trustworthy reasoning from certain other propositions or axioms, which are supposed to be still more elementary. If these axioms are true, the proposition is true; if the axioms are not true, the proposition is not true from university. Whether the axioms are true or not I cannot say, and it is outside my province to consider.

→ I think the claim has been generally abandoned. [Euclid]

→ Physicist is more Interested in Euclidean geometry than in any other, and is continually setting us problems in it.

→ We have tended to give an undue share of attention to the Euclidean system.

→ By taking a very large number of typical cases, and I am limited by the inevitable inaccuracies of experiment;

→ By taking a very large number of typical cases, and I'm limited by the inevitable. / In

→ I was speaking of a proposition of geometry properties of space, not of matter.
How a material scale behaves when you turn it into different positions.

→ Measures with an optical device.

→ Speaking of properties of light.

→ By length and distance you always mean a quantity arrived at by measurements with material or optical appliances.

→ "Natural geometry" → which the brain of mathematicians has invented.

→

→ If you explore a magnetic needle, you find out the magnetic field. What we may call the field of extension, or space-field, is just as much a physical quality as the magnetic field. You can think of them both existing together in the aether, if you like.

→ As to how far space really resembles a magnetic field, I do not wish to dogmatise.

→ Length must be measured in a rigid scale.

→ Important addition to our definition of length. But what is a rigid scale? → A scale which always keeps the same length

→

→ No, you must not define length by means of a rigid scale, and define a rigid scale by means of length.

→ Heaven forbid

→ definite, direct in trying to arrive at the exact meaning of length. When you claim to determine lengths to eight significant figures, you must have a pretty definite standard of right and wrong measurements.

→ Difficult to define what we mean by rigid.

[illegible] was the standard of length. It could not change length

→ [illegible] or at least approachable.

→ Can define these defects without appealing to any extraneous definition of length.

• We must recognise then that all our knowledge of space rests on the behaviour of natural measuring-scales free from certain definable defects of constitution.

→ Amount in given length is constant.

→ Ordinarily [illegible] simply means that the same amount of space corresponds to each [illegible] of your rigid measuring [illegible].

→ Anything without measurements and measurement involves some specified material appliance.

→ In a very intense gravitational field.

→ No knowledge of space apart from my measures, and I have no better standard than the rigid rod.
Difficult to see what the corrected measures would mean.
Failure of the proposition was due to the measures going wrong than to an alteration in the character of space.

→ Space which is superior to measurement.
→ Ready to throw the measures rather than let the space be distorted.

→ It was the standard of length, It could not change length.

→ attainable, or at least approachable.

→ Can define these defects without appealing to any extraneous determination of length.

∘ We must recognise then that all our knowledge of space rests on the behaviour of material measuring-scales free from certain definable defects of constitution.

→ Amount in given length is constant.

→ Uniformity mean only means that the same amount of space corresponds to each inch of your rigid measuring scale used.

→ Anything without measurement and measurement involves some specified material appliance.

→ In a very intense gravitational field.

→ No knowledge of space apart from my measures, and I have no better standard than the rigid rod.
difficult to see what the corrected measures would mean.
failure of the proportion was due to the measures going wrong than to an alteration in the character of space.

→ Space which is superior to measurement.
→ Ready to throw the measures rather than let the space be distorted.

→ Mathematically and Conceptually Euclidean and non-Euclidean space are on the same footing; our preference for Euclidean space was based on Measures, and must stand or fall by Measures.

→ I am trying to measure something called length, which has an absolute meaning in nature, and is of importance in connection with the laws of nature. ~~and is~~

→ Rigid rod determines it accurately when no disturbance like gravitation is present.

→ Hypotheses ① There is an absolute thing in nature corresponding to length.
② The geometry of these absolute lengths is Euclidean.
③ Practical measures determine the length accurately when there is no gravitational force.

→ Is there some absolute quantity in nature that we try to determine when we measure lengths?

→ Counting appears to be an absolute operation.

→ Any physical quantity, which is not a pure number, can only be defined as the result arrived at by conducting a physical experiment according to specified rules.

→ If so, it will turn up in due course in our theoretical formulae.

→ Laws for it to obey, on the off-chance of it's proving

→ Natural geometry is the theory of the behaviour of material scales.

→ In natural geometry is an assertion as to the behaviour of rigid scales because that implies a standard of rigidity which does not exist.

→ The space which you are speaking of must be a sort of abstraction of the extensional relations of matter.

→ Whenever we investigate the properties of space experimentally, it is these extensional relations that we are finding.
Conclude that space as known as to us must be the abstraction of these natural relations, and not something more transcendental.

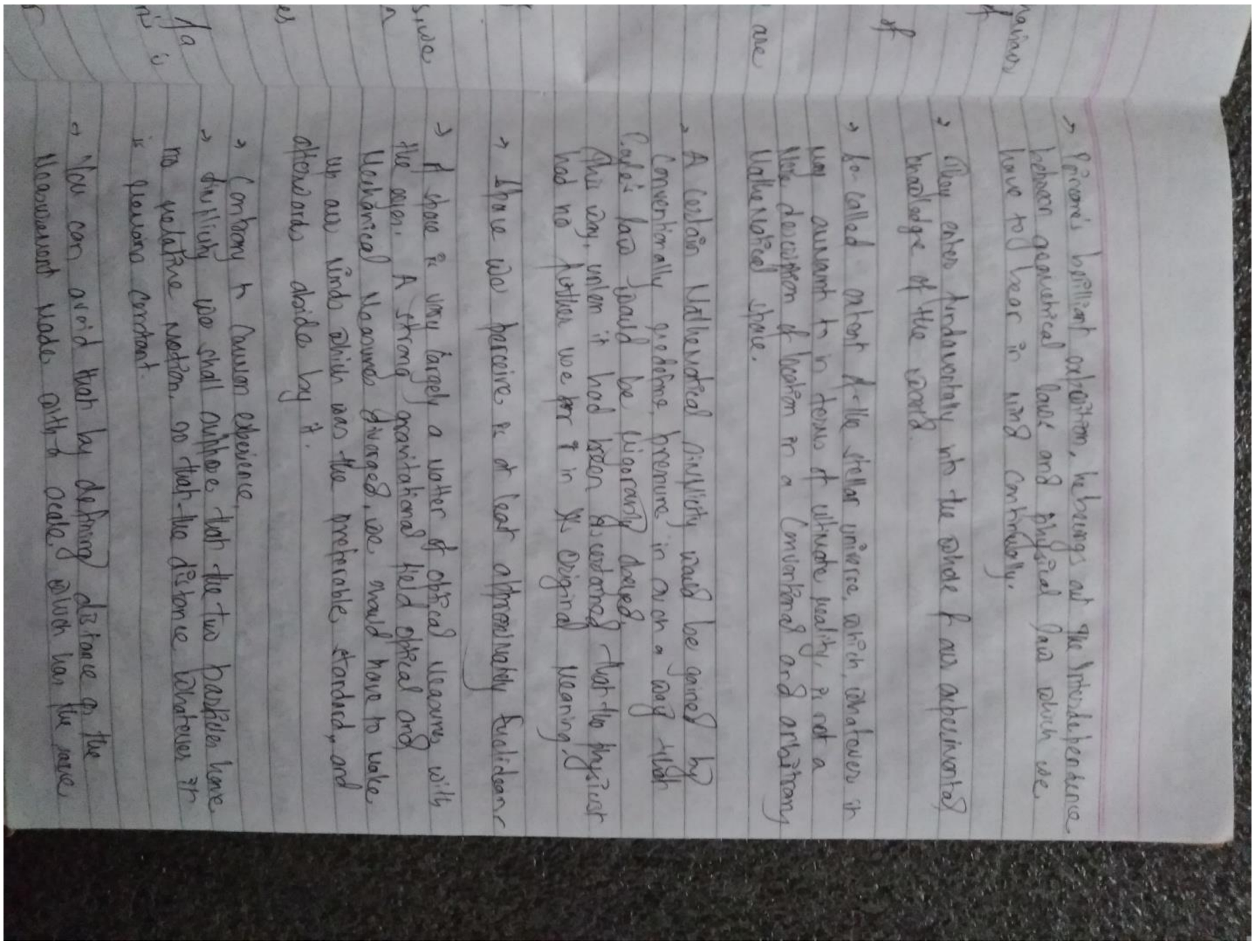
→ Doubtful whether this abstraction of extensional relations quite fulfils your general idea of space, and, as a necessity of thought, you require something beyond.

→ It is not the properties of this more transcendental things we are speaking of when we describe geometry as Euclidean or non-Euclidean.

→ The view has been widely held that space is neither physical nor metaphysical, but conventional.

→ If Lobatchewsky's geometry is true, the parallax of a very distant star will be finite. If Riemann's is true, it will be negative.

→ Euclidean geometry, therefore, has nothing to fear from fresh experiment.


→ Poincaré's brilliant exposition, he brings out the interdependence between geometrical laws and physical laws which we have to bear in mind continually.

→ They enter fundamentally into the whole of our experimental knowledge of the world.

→ So-called extent of the stellar universe, which, whatever it may amount to in terms of ultimate reality, is not a mere description of location in a conventional and arbitrary mathematical space.

→ A certain mathematical simplicity would be gained by conventionally redefining pressure in such a way that Boyle's law would be rigorously obeyed.
This way, unless it had been ascertained that the physicist had no further use for it in its original meaning.

→ Space we perceive is at least approximately Euclidean.

→ A space is very largely a matter of optical measures with the eyes. A strong gravitational field optical and mechanical measures diverged, we should have to make up our minds which was the preferable standard, and afterwards abide by it.

→ Contrary to common experience.
→ Simplicity we shall suppose that the two particles have no relative motion, so that the distance whatever it is remains constant.

→ You can avoid that by defining distance as the measurement made with a scale which has the same

Actually as the two points then, they will always be in contact with two particular divisions of the scale.

→ When the relativist wishes to refer to this length, he calls it the proper length; in non-relativity physics it does not seem to have been used at all.

→ What is the same moment at different places? The conception of simultaneity in different places is a difficult one.

→ At a very modest reckoning the motion of the earth in the interval might alter the light time by several days.

→ There is no simultaneity.

→ It is better therefore, not to base our physics on the notion of absolute simultaneity, which may turn out not to exist, and is in any case out of reach at present.

→ The fundamental measurement is not the interval between two points of space, but between two points of space associated with instants of time.

→ We shall need a perfect clock as well as a rigid scale for our measures.

→ Best theoretical clock, as well would be a tube of light travelling in vacuum to and fro between mirrors at the two ends of a rigid scale. The instants of arrival at one end would define equal intervals of time.

- Then you are comparing it with some notion of absolute time.

- You must remember too that if you wish to measure a second at one place, you must keep your clock fixed at what you consider to be one place; so the notion is defined. The necessity of defining the notion of the clock emphasises that one cannot consider time apart from space; there is no geometry combining both.

- It is only necessary to consider time as a fourth dimension.

- Your use of the term dimensions is probably very more restricted than mine.

- But is it not going rather far to say that geometry can deal directly with these things and is not necessarily concerned with lengths in space?

- Though he has defined carefully how they are to be measured he has certainly not conveyed to me any notion of how I am to picture them. If my picture of absolute space is an illusion.

- That is an excellent description of Pure Mathematics, which has already been given by an eminent Mathematician, "Mathematics may be defined as the subject in which we never know what we are talking about, nor whether what we are saying is true."

- In which time is a fourth dimension as distinct from a fourth variable. The term dimension seems to be associated

with relations of order.

→ We may split it arbitrarily into space and time, just as we can split the order of space into length, breadth and thickness. But space without time is as incomplete as a surface without thickness.

→ One cannot predict the ultimate number of dimensions in the world if indeed the expression dimensions is applicable.

→ In Physics the question is whether motion through aether has any meaning?

→ 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 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.

→ The relativist sees no reason to change the rules of the game because the result does not agree with previous anticipation. Accordingly, when he 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; and, moreover, it is the space of everyday perception. If his right to appropriate the term space in this way is challenged, he would urge that this is the sense in which the term has always been used in physics hitherto. It is only recently that conservative physicists, frightened by the revolutionary consequence

of Modern experiments, have begun to play with the idea of a pre-existing space whose properties cannot be ascertained by experiment a (Metaphysical space).

⇒ The relativist in defining space as Measured space, clearly recognises that all experiment Measurement involves the use of Material apparatus the resulting system geometry is specifically a study of the extensional relations of Matter. He declines to Consider anything more transcendental

⇒ Since natural geometry is the study of extensional relations of natural objects, and since it is found that their space order cannot be discussed without reference to their time-order as well, it has become necessary to extend our geometry to four dimensions in order to Include time.

Chap-1

The FitzGerald Contraction

→ Will it takes longer to swim to a point 100 yards up-stream and back, or to a point 100 yards across-stream and back?

→ The up and down swim is thus longer than the transverse swim in the ..

→ M-M exp:- There was an optical device for studying interference fringes; because the recomposition of two waves after the journey would reveal if one had been delayed more than the other so that, for example, the crest of one instead of fitting on to crest of other coincided with its trough, and the result was dead heat.

→ Why does light seem to behave differently?

→ The straightforward interpretation of this remarkable result is that each course undergoes an automatic contraction when it is swung from the transverse to the longitudinal position, so that whichever arm of the apparatus is placed up-stream it straightway becomes shorter.

→ If we have two competitors, one of whom is known to be slower than the other, and yet they both arrive at the winning post at the same time, it is clear that they cannot have travelled equal courses.

→ The contraction must be the same for all kinds of matter; the expected delay depends only on the ratio of the speed of the aether current to the speed of light and the contraction which compensates it must be equally definite.

→ Under Ordinary Circumstances the form and size of a solid body is maintained by the forces of Collision between the particles.

→ When the flow changes there will be a readjustment of cohesive forces, and we must to expect the body to take a new shape and size.

→ Taking the accepted formulae of E.M theory (Larmor & Lorentz), they showed that the new form of equilibrium would be contracted in just such a way and by just such an amount as Fitzgerald's explanation.*

→ The M-M experiment has thus failed to detect our Motion through the aether, because the effect looked for, the delay of one of the lightwaves - is exactly compensated by an automatic contraction of the Matter forming the apparatus.

→ We can only experiment with the small range of velocity caused by the earth's orbital Motion.

→ Restricted Principle of Relativity :→ It is Impossible by any experiment to detect the uniform Motion relative to the aether.

→ It would show that there is some standard of rest with respect to which the law of gravitation takes a symmetrical and simple form; presumably this standard corresponds to some gravitational Medium and the Motion determined would be Motion with respect to that Medium.

→ The aether defined as the seat of electric force. Must be revealed, if at all, by electric phenomena.

→ The Newtonian Dynamics the phenomena are independent of uniform motion of the system; no explanation is asked for because it is difficult to see any reason why there should be an effect.

→ For Fitzgerald Contraction:→ What you perceive is an image of the rod on the retina of your eye; you imagine that the image occupies the same space in both positions, but your posterior retina has contracted in the vertical direction without your knowing it, so that your visual estimates of vertical length are double what they should be.

→ Because everything is altered in the same way, nothing appears to be altered at all.

→ 77-90.

→ To avoid distortion of the retina, lie on your back on the floor, and watch in a suitably inclined mirror someone turn the rod from the horizontal to the vertical position. You will, of course, see no change of length, and it is not possible to blame the retina this time. But is the appearance in the mirror a faithful reproduction of what is actually occurring?, In a plane mirror at least the appearance is correct.

→ We know that the complete compensations is inherent in the fundamental laws of nature, and so must occur in every case.

→ We shall suppose a flying man that he is in a comfortable travelling conveyance in which he can move about and act normally and that his length is in the direction of the flight. If we could catch an instantaneous glimpse as he passed, we should see a fig. about three feet high, but with the breadth and girth of a normal human being. And the strange thing is that he would be sublimely unconscious of his own dignified appearance. If he looks in a mirror in his conveyance, he sees his usual proportions; this is because of the contraction of his retina, or the distortion by the moving mirror, as already explained. But when he looks down on us, he sees a strange race of men who have gone apparently gone through some flattening-out process: one ~~of~~ man looks barely 10 inches across the shoulders, another standing at right angles is almost "length and breadth without thickness".

→ It is the reciprocity of these appearances that each party should think the other has contracted - that is so difficult to realise.

→ This reciprocity is easily seen to be a necessary consequence of the principle of relativity.

→ It is not illusion in the ordinary sense, because the impressions of both would be confirmed by every physical test or scientific calculation suggested. No one knows which is right. No one will ever know, because we can never find out which, if either, is truly at rest in the aether.

→ It is not only in space but in time these strange variations occur.

→ Extravagant slowing of time

→ Because the aviator is rapidly increasing his distance from us and the light-impressions take longer and longer to reach us.

→ But here again reciprocity comes in, because in the aviator's ~~opti~~ opinion it is we who are travelling at 161,000 miles a second past him; and when he has made all allowances he finds that it is we who are ~~[illegible]~~ sluggish. Our cigar lasts twice as long as his.

→ The aviator knows, of course, that this is not the true time when our cigar was finished, and that he must correct for the ~~[illegible]~~ true time when our cigar was finished. He sets himself this problem – that man has travelled away from me at 161,000 miles a second for an unknown time "x" minutes: he has then sent a signal which travels the same distance back at 186,000 miles a second.

→ Makes out that he was wrong in his inference and we were right. But no one can tell which was really right.

→ Paradox is that we assume that we are at rest in the aether, whereas the aviator assumes that he is at rest.

→ length in the direction of flight became smaller and smaller, until for the speed of light they shrunk to zero.

→ because nothin' goes on

→ So long as he travels with the speed of light, he has Immortality and eternal youth.

→ If the aviator could detect anything in his Measurements Inconsistent with the hypothesis that he was at rest in the aether (e.g. a difference of velocity of overtaking waves of light and waves meeting him) it would contradict the restricted principle of relativity.

→ Since the earth is moving relatively to our adventurer with the velocity of flight, we might be tempted to argue that from this point of view the terrestrial observer would have perpetual youth whilst the voyager grew older. Evidently, if they meet again, they could disprove one or other of the two arguments. But in order to meet again the velocity of one of them must be reversed by supernatural means or by an intense gravitational force so that the conditions are not symmetrical and reciprocity does not apply. The argument given in the text appears to be the correct one.

→ The relativist is sometimes suspected of an inordinate fondness for paradox; but that is rather a misunderstanding of his argument.

→ On any planet moving with a great velocity through the aether, extraordinary changes of length of objects are continually occurring as they move about, and there is a slowing down of all natural processes as though time were retarded. But similar effects would be detected by any observer having a great velocity relative to the planet.*

→ There is complete reciprocity so that each of two observers in relative motion will find the same strange phenomena occurring to the other, and there is nothing to help us to decide which is right.

→ Distinction between the principle and the standpoint of relativity. The principle of relativity is a statement of experimental fact, which may be right or wrong; the first part of it - the restricted principle, - has already been enunciated. Its consequences can be deduced by mathematical reasoning.

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The correction applied for light transmission will naturally be based on the direct or an experimental determination of the velocity of light.

→ The standpoint of relativity is of a different character. It asserts first that certain unproved hypotheses as to time and space have insensibly crept into current physical theories, and that these are the source of the difficulties described above.

And it discovers that they are quite necessary and are not supported by any known fact. That in itself appears to be sufficient justification for the standpoint. Even if at some future time facts should be discovered which confirms the rejected hypotheses, the relativist is not wrong in discarding them until they are required.

→ But to those who think that the relativity theory is a passing phase of scientific thought, which may be reversed in the light of future experimental discoveries, we would point out that, though like other theories it may be developed and corrected, there is a certain minimum statement possible which represents irreversible progress.

→ It can now be proved that these hypotheses have nothing to do with any phenomena yet observed, and do not afford explanations of any unknown fact.

→ The relativity standpoint is then a discarding of certain hypotheses, which are uncalled for by any known facts, and stand in the way of an understanding of the simplicity of nature.

Chap - 2

Relativity

→ There are two parties to every observation — the observed and the observer.

→ The picture of the world so obtained is none the less relative. We have not eliminated the observer's share; we have only fixed it definitely.

→ It may well require a complete change in our apparatus of description because all the familiar terms of physics refer primarily to the relations of the world to an observer in some specified circumstances.

→ But they lie outside the normal scope of physics.

→ The circumstances of any observer which affect his observations are his position, motion and gauge of magnitude.

→ Position, motion, magnitude-scale these factors have a profound influence on the aspect of the world to us.

→ If we had been endowed with two eyes moving with different velocities our brains would have developed the necessary faculty; we should have perceived a kind of relief in a fourth dimension so as to combine into one picture the aspect of things seen with different motions.

→ As lodge has said, Our senses were developed by the struggle for existence, not for the purpose of philosophising on the world.

→ A relative change of scale of observer and observed.

→ that the observer had changed.

→ Our standard of size - the rigid measuring rod must change according to the circumstances of its motion; and the aviator's adventures illustrated a similar change in the standard of duration of time.

→ The object of the relativity theory - was to emphasise that in our ordinary description and in our scientific ~~observation~~ description of natural phenomena, the two factors are indissolubly united.

→ And it remains to be seen whether any of them can be retained in a description of the world, which is not relative to a particular observer.

→ Our first task is a description of the world independent of the motion of the observer.

→ That duration of time also requires that an observer should be specified.

→ Thus length and duration are not things inherent in the external world.

→ When the rod in Michelson-Morley experiment is turned through a right angle it contracts; that naturally gives the impression that something has happened to the rod itself.

→ Its length has altered, but length is not an intrinsic property of the rod, since it is quite indeterminate until some observer is specified. Turning the rod through a right angle has altered the relation to the observer, but the rod itself, or the relation of a Molecule at one end to a Molecule at the other, is unchanged.

→ All observers are not to be regarded as on the same footing, and that there is some absolute observer, because nature pays attention to his space-time position.

→ Evidently our proper course is to pursue our investigation, and call in this hypothetical observer only if we find there is something which he can help to explain.

→ The answer is that we believe that the phenomena do occur as described; only the description (like that of all observed phenomena) concerns the relations of the external world to some observer, and not the external world itself. The startling character of the phenomena arises from the natural but fallacious inference that they involve intrinsic changes in the objects themselves.

→ Although length and duration have no exact counterparts in the external world, it is clear that there is a certain ordering of things and events outside us which we must now find more appropriate terms to describe.

→ It does not imply that there is no distinction between space and time; but it gives a fresh unbiased start by which to determine what the nature of the distinction is.

→ The solid block is the true analogy for the 4-D combination of space-time; it does not separate naturally into a particular set of three-D spaces piled in fourfold order. It can be quadrisected into rows of pile, but it can be redivided in any direction we please.

→ So the observer by changing his motion makes a new division of 4-D order into time and space.

→ It indicates that observers with different motions will have different time and space reckoning — a conclusion we have already reached from another point of view.

→ They all agree that the order of events is 4-fold, and it appears that this undivided 4-fold order is the same for all observers.

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→ So we resolve extension in the 4-D world, into length and duration.
Whereas length and duration are relative, the single "extension" of which they are components has an absolute significance in nature, independent of the particular decomposition into space and time separately adopted by the observer.

→ If he alters one component he must necessarily alter the other; so he will make the time-component differ slightly from an hour. By analogy with resolution into components in 3-D, we should expect him to make it less than an hour, having, as it were, borrowed from time to make space; but as a matter of fact he makes it longer.

→ What determines the separation of space and time for any particular observer can now be seen.

→ Since any separation of space and time is admissible, it is possible for the astronomer to base his space and time on the track of a solar observer instead of that of a terrestrial observer; but it must be remembered that in practice the space and time of the solar observer have to be inferred indirectly from those of the terrestrial observer; and, if the corrections are made according to the crude methods hitherto employed, they may be inferred wrongly (if extreme accuracy is needed).

→ We do deny that the aether need have such properties as to separate space and time in the way supposed.

→ A modern writer on E.M. theory will generally start with the postulate of an aether pervading all space; he will then explain that at any point in it there is an E.M. vector whose intensity can be measured; henceforth his sole dealings are with the vector, and probably nothing more will be heard of the aether itself.

→ Accordingly Newton's laws of mechanics are not of the general type in which it is unnecessary to particularise the observer; they hold only for observers with a special kind of motion which is described as "unaccelerated". The only definition of this epithet that can be given is that an "unaccelerated" observer is one for whom Newton's laws of motion hold.

→ It was pointed out by Newton that, whereas there is no criterion for detecting whether a body is at rest or uniform motion, it is easy to detect whether it is in rotation.

→ This problem of rotation affords a hint as to the cause of the incomplete relativity of Newtonian Dynamics. The laws of motion are formulated for an unaccelerated observer and do not apply to a frame of reference rotating with the earth.

→ Since the effect of deviation from Newton's standard frame is the introduction of a field of force, the generalized relativity theory must be largely concerned with the nature of fields of force.

→ Similarly, if in empty space we choose a frame of reference which more or less traces the lines of the absolute structure in the region, the frame will usurp some of the absolute qualities of that structure. What we mean by the equivalence of all frames is that they are not differentiated by any qualities formerly supposed to be intrinsic in the frames themselves — rest, rectangularity, acceleration, independent of the absolute structure of the world that is referred to them.

→ It is possible for a frame of reference to acquire absolute properties, but that the Newtonian frame has been laid down on the basis of relative knowledge, without any attempt to follow the lines of absolute structure.

→ Newton's view assumes that there is such a counterpart an active cause in nature which is identical with the force perceived by his standard unaccelerated observer.

→ We shall have to study the nature of this unknown

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relation to us appear as fine.

→ The absolute world is of so different a nature, that the relative world, with which we are acquainted, seems like almost like a dream.

→ We do not suggest that physicists ought to translate their results into terms of (4-D) space for the empty satisfaction of working in the realm of reality.

2nd [World of 4-D] , 4*

→ Vertically is not a universally differentiated direction in space, as the flat-earth philosophers might have imagined. Similarly by combining the time-ordering and space-ordering of the events of nature into a single order of four dimensions, we shall not only obtain greater simplicity for the phenomena in which the seperation of time and space is irrelevant, but we shall understand better the nature of the differentiation when it is relevant.

→ An event in it's customary meaning would be the physical happening which occurs at and identifies a particular place and time.

→ In the ordinary geometry of two or three dimensions, the distance between two points is something which can be measured, usually with a rigid scale; it is supposed to be the same for all observers, and there is no need to specify horizontal and vertical directions or a particular system of co ordinates.

→ The extension in space and time combined is called the interval between the two events; it is the same for all observers, however they resolve it into space and time separately.

→ An important point arises here. But how are we to use the same scale for measuring 't'? The most common natural connection between the measure of time and length is given by the fact that light travels $3 \times 10^8 \, m s^{-1}$.

→ We make the velocity of light the unity of velocity. It is not essential to do, but it greatly simplifies the discussion.

→ The formulae here given for s^2 are the characteristic formulae of Euclidean geometry.

→ But space-time is not Euclidean; it does, however, conform to a very simple modification of Euclidean geometry indicated by the corrected formulae.

$$s^2 = (x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2 - (t_2 - t_1)^2$$

There is only a sign altered; but that minus sign is the secret of the differences of the manifestations of time and space in nature.
This change of sign is often found puzzling at the start. We could not define 's' by the expression originally proposed (with the positive signs), because the expression does not define anything objective. Using the space and time of one observer, one value is obtained; for another observer, another value is obtained. But if s is defined by the expression now given, it is

found that the same result is obtained by all observers, the quantity s is thus something which concerns solely the two events chosen; we give it a name - the Interval between the two events.

→ Hence Interval, as here defined, is the analogue of distance; and the analogy is strengthened by the evident resemblance of the formula for s in both cases. Moreover, when the difference of time vanishes, the Interval reduces to the distance. But the discrepancy of sign introduces certain important differences. → The geometry of ~~Euclide~~ space is Euclidean, but the geometry of space-time is semi-Euclidean or "hyperbolic."

$$t = \tau\sqrt{-1}. \quad \text{Imaginary time}$$

$$\Rightarrow (t_2 - t_1)^2 = -(\tau_2 - \tau_1)^2;$$

so that. $s^2 = (x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2 + (\tau_2 - \tau_1)^2$

→ Everything is now symmetrical and there is no distinction between τ and other variables. The continuum formed of space and imaginary time as is completely isotropic for all measurements; no direction can be picked out in it as fundamentally distinct from any other.

→ The observer's separation of this continuum into space and time consists in slicing it in some direction, viz, that perpendicular to the path along which he is himself travelling; and the perpendicular dimension is (imaginary) time.

→ Corresponds to an orientation of the ~~space~~ time-axis along his own course in the 4-D world, whereas the ~~geometry~~ ordinary time and space are given when the time-axis is oriented along the course of a terrestrial observer. The FitzGerald contraction and the change of time-measurement are given exactly by the

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→ factor $\sqrt{-1}$, which seems to have the property of turning time into space. It can scarcely be regarded as more than an analytical device. To follow out the theory of the four-dimensional world in more detail, it is necessary to return to real time, and face the difficulties of a strange geometry.

→ One dimension of the space will be represented by horizontal distance parallel to OX; another will stand out at right angles from the page; and the reader must imagine the third as best he can.

→ We limit ourselves to motion to and fro in one straight line in space.

→ Hence U'OU, V'OV will be the track of pulses of light in opposite directions along the straight line.

→ To have actual evidence of the occurrence of one event before experiencing the second is a clear proof of their absolute order in nature, which should convince not merely the observer concerned but any other observer with whom he can communicate.

→ An observer experiencing the event P could not get news of the event O by any known means until after P had happened. The order of the two events can therefore only be inferred by estimating the delay of the message, and this estimate will depend on the observer's mode of reckoning space and time.

→ Space-time is divided into three zones w.r.t. the event O.

→ VOV' and VOV' are (absolutely) neither past nor future, but only "elsewhere".

→ But the events O and P' cannot happen to the same particles and no observer could regard them as happening at the same place. The main interest of this analysis is that it ~~follows~~ shows that the arbitrariness of time-direction is not inconsistent with the existence of regions of absolute past and future.

→ The denial of absolute simultaneity is a natural complement to the denial of absolute motion. The latter asserts that we cannot find out what is the same time at two different places.

→ The division of into past and future (a feature of time-order which has no analogy in space-order) is closely associated with our ideas of causation and free will.

→ Events do not happen; they are just there, and we come across them.

→ A detached observer contemplating ~~out~~ our world sees some events apparently causing events in their future, others apparently causing events in their past the truth being that all are linked by determinate laws, the so-called causal events being merely conspicuous foci from which the links radiate.

→ If the events P could be determined by the event O, and was not predetermined by causes anterior to both, if it was possible for it to happen or not, consistently with the laws of nature.

→ But it is of interest to show that the theory of 4-D space-time provides an absolute past and future, in accordance with causal requirements, although this can usually be ignored in applications to physics.

→ We have changed the sign of s^2 because usually ~~(both~~ (though not always) the original s^2 would have come out negative. In Euclidean space points distant a unit interval lie on a circle, but, owing to the change in geometry due to the altered sign of $(t_2 - t_1)^2$, they now lie on a rectangular hyperbola with two branches KLM, K'L'M'.

→ Now make the following construction; draw a straight line OFP, to meet the hyperbola in F, draw the tangent FG at F, meeting the light-line U'OU in G; complete the parallelogram OFGH; produce OH to X_1.

→ It can be shown from the properties of the hyperbola that the locus of points at any interval 's' from O, given by equation 1) viz.

$$s^2 = (t - t_0)^2 - (x - x_0)^2$$

is the same locus (a hyperbola) for both systems of reckoning x and t.

The two observers will always agree on the measures of intervals, though they will disagree about lengths, durations and the velocities of everything except light. This rather complex transformation is mathematically equivalent to the simple rotation of the axes required when imaginary time is used.

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→ It cannot be said that either observer's space-time is distorted absolutely, but one is distorted relatively to the other. It is the relation of order, which is intrinsic in nature, and is the same both for the squares and diamonds; shape is put into nature by the observer when he has chosen his ~~partons~~ partition.

→ Thus S judges it to have contracted on account of ~~its~~ motion relative to him.

→ In the limit, when the velocity reaches that of light, both space-unit and time-unit become infinite, so that in the natural units for an observer travelling with the speed of light, all the events in the finite experience of S take place "in no time" and the size of every object is zero.

→ Consequently for an observer travelling with the speed of light all ordinary objects become two-dimensional, preserving their lateral dimensions, but infinitely thin longitudinally. The fact that events take place "in no time" is usually explained by saying that the inertia of any particle moving with the velocity of light becomes infinite so that all molecular processes in the observer must stop; many things may happen in S's world in a twinkling of an eye of S's eye.

→ "At the back of your mind, you know that a fourth dimension is all nonsense."

→ That time is a fourth dimension may suggest unnecessary difficulties which a more precise definition avoids.

S

→ Just in that process of relation to an Individual, the order falls apart into the distinct Manifestations of space and time. An Individual is a 4-D object of greatly elongated form; in ordinary language we say that he has considerable extension in time and insignificant extension of space. Practically he is represented by a line - his track through the world. When the world is related to such an Individual, his own asymmetry is introduced into the relation; and that order of events which is parallel with his tracks that is to say with himself, appears in his experience to be differentiated from all other orders of events.

S

1) As a 4-D body moves, its section by the 3-D world may vary; thus a rigid body can alter size and shape.

3) It should be possible to see the Inside of a solid, just as we can see the Inside of the square by viewing it from a point outside its plane.

2) It should be possible for a body to enter a completely closed room, by travelling into it, in the direction of the fourth dimension, just as we can bring our pencil down on to any point within a square without crossing its order.

↓

→ The first phenomenon is Manifested by Fitzgerald Contraction.

→ If the quantity of Matter is to be identified with its Mass, the ~~third~~ then second phenomena does not happen. It could happen, but it does not happen.

3) The third phenomenon does not happen for two reasons.

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A natural body extends in time as well as in space, and is therefore 4-D, but for the analogy to hold, the object must have one dimension less than the world, like the square seen from the third dimension.

→ Light tracks in 4-D are restricted to certain lines, like OV', U'OV', whereas in 3-D light can transverse any straight line. This could be remedied by interposing some kind of dispersive medium, so that light of some wave length could be found travelling with every velocity and following every track in space-time; then, looking at a solid which suddenly went out of existence, we should receive at the same moment light-impressions from every particle in its interior (supposing them self-luminous). We actually should see the inside of it.

→ The interval is a quantity so fundamental for us that we may consider its measurement in some detail.

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→ When the clocks are correctly set and viewed from A the sum of the readings of any clock and the division beside it is the same for all, since the scale-reading gives the correction for the time taken by light, travelling with unit velocity, to reach A.

→ Then the divisions would have advanced to meet the second event, and (x_2-x_1) would be smaller. This is compensated, because (t_2-t_1) also becomes altered. A is now advancing to meet the light coming from any of the clocks along the rod; the light arrives too quickly, and in little the initial adjustment described above the clock must be set back a little.

→ There are other small corrections arising from the FitzGerald Contraction, etc.; and the net result is that, it does not matter what uniform motion is given to the scale, the final result for S, is always the same.

→ When B measures C's velocity relative to him, he uses his own space and time, and it must be corrected to reduce to A's space and time units, before it can be added on to a velocity measured by A.

→ If we contain the chain, introducing D whose velocity relative to C, and measured by C, is 100 km. per sec and so on ad infinitum, we never obtain an infinite velocity with respect to A, but gradually approach the limiting velocity of 3×10^8 m sec^{-1}. ie 'c'.

→ But, if a speed of 3×10^8 m sec^{-1} is mentioned, there is no need to ask the question; the answer is relative to any and every piece of matter.

→ The velocity of light plays a conspicuous part in the relativity theory.

→ The fact that the velocity of light is the same for all ~~Characters~~ observers is a consequence rather than a cause of its pre-eminent character.

→ So that in practice our determinations of simultaneity depend on signals transmitted with this speed. If some new kind of ray with a higher speed were discovered, it would perhaps tend to displace light signals and light-velocity in this part of the work, the reckoning being modified to correspond; on the other hand

This would lead to displace light-signals and light-velocity in this part of the world, time-reckoning being modified to correspond; on the other hand, this would lead to greater complexity in the formulae, because the FitzGerald Contraction, which affects space-measurements depends on light-velocity.

→ The material structure of the four-dimensional world is fibrous, with the threads all running along time-like tracks; it is a tangled warp without a woof. Hence, even if the discovery of a new ray led us to modify the reckoning of time and space, it would still be necessary in the study of material systems to preserve the present absolute distinctions of ~~space~~ time-like and space-like intervals, under a new name if necessary.

→ It can scarcely be said to be a self-contradictory property to be in two places at the same time any more than for an object to be at two times in the same place. The perplexities of the quantum theory of energy sometimes seem to suggest that the possibility ought not to be overlooked; but, on the whole, the evidence seems to be against the existence of anything moving with a speed beyond that of light.

→ Our only reference to electrical theory has been in connection with Larmor and Lorentz's explanation of FitzGerald Contraction; but now from the discussion of 4-D world, we have found a more general explanation of the change of length.

Here
→ J.J. Thomson that if a charged ~~particle~~ conductor is to be moved or stopped, additional effort will be necessary simply on account of the charge. The conductor has to carry its electric field with it and force is needed to set the field moving. This property is called Inertia.

and it is Measured by Mass. If, keeping the Charge Constant, the size of the Conductor is diminished, this Inertia Increases.

→ When the Calculations are extended to Charges Moving with high Velocities, It is found that the electrical Inertia is not strictly Constant but depends on the speed; in all cases the variations is summed up in the statement that the Inertia is simply proportional to the total energy of the electromagnetic field. We can say, if we like the Mass of a charged particle at rest belongs to its electrostatic energy; when the charge is set in Motion, K.E. is added, and this K.E. also has Mass.

→ Presumably the gravitational energy has Mass; or, if not, Mass will be created when, as often happens, gravitational energy is Converted into K.E. The Mass of the whole (negative) gravitational energy of the earth is of the order minus a billion tons.

→ The theoretical Increase of the Mass of an electron with speed has been Confirmed experimentally, the agreement with calculations being perfect if the electron undergoes the FitzGerald Contraction by its Motion. This has been held to Indicate that the electron cannot have any Inertia other than that due to the electromagnetic field carried by it. But the Conclusion (though probable enough) is not a fair Inference; because these results, obtained by special Calculations for electrical Inertia, are found to be predicted by STR for any kind of Inertia.

→ The factor giving the Increase the mass with speed is the same as that which affects length and time. Thus if a rod

Moves at such a speed that its length is halved, its mass it will be doubled. Its density will be increased four fold since, it is both heavier and less in volume.

→ We have thought it necessary to include this brief summary of the electrical theory of matter and mass, because, although it is not required by the relativity theory, it is so universally accepted in physics that we can scarcely ignore it.

→ But since the experimental measurement of inertia involves the study of a body in non uniform motion, it is not possible to enter on a satisfactory discussion of mass until the more general theory of relativity for non-uniform motion has been developed.

Fields of force :-

[· On the other hand, empty void cannot offer resistance to anything in any direction at any time, but must, as its nature craves, continually give way; and for this reason all things must be moved]:-.

→ The scientific measure of a force is the momentum that it communicates to a body in given time.

→ Modern physics show that the ~~bombard~~ momentum is communicated by a process of molecular bombardment.

→ Gravitation is not resolvable into a succession of molecular blows. A massive body, such as the earth, seems to be surrounded by a field of latent force, ready, if another body enters the field, to become active and transmit motion.

→ Recent discovery that gravitation acts not only on the Molecules of Matter, but on the undulations of light.

→ That in a limited region it is possible to create an artificial field of force which imitates a natural gravitational field so exactly that, so far as experiments have yet gone, no one can tell the difference.

→ Increased weight is not only a matter of sensation; it is shown by any physical experiments that can be performed.

→ Values of "g", the acceleration due to gravity, at different latitudes. But the numbers given do not relate to gravity alone; they are the resultant of gravity and the centrifugal force of the earth's rotation.

→ Similar artificial fields are produced when an aeroplane changes it's course or speed; and one of the difficulties of navigation is the impossibility of discriminating between these and the true gravitation of the earth with which they combine. One usually finds that the practical aviator requires little persuasion of the relativity of force.

→ It must be remembered that straight ~~line~~ in the 4-D world, means something more than straight in space; it implies also uniform velocity, since the velocity determines the inclination of the track to the time-axis.

→ Presently the speed of ~~light~~ the lift becomes uniform and the track in the diagram becomes straight. So long as the track is curved (accelerated motion), a field of forces is perceived; it disappears when the track becomes straight (uniform motion).

→ Again the observer on the earth is carried round in a circle, once a day by the earth's rotation; allowing for steady progress through time, the track in 4-D is spiral.

→ Artificial field of force is associated with curvature of track, and we can lay down the following rule:
Whenever the observer's track through the 4-D world is curved he perceives an artificial field of force.

→ The field of force is not only perceived by the observer in his sensation, but reveals itself in his physical measures. It should be understood, however, that the curvature of track must not have been otherwise allowed for.

→ The centrifugal force is made to disappear if we choose a suitable standard observer not rotating with the earth; the gravitational force was made to disappear when we ~~choose~~ chose as standard observer an occupant of Jule Verne falling projectile. If the possibility of annulling a field of force by choosing a suitable standard observer is a test of unreality, then gravitation is equally unreal with centrifugal force.

→ When we choose the non-rotating observer the centrifugal force disappears completely and everywhere. When we choose the occupant of the falling ~~project~~ projectile, gravitation disappears in his immediate neighbourhood; but he would notice that, although unsupported objects round him experienced no acceleration relative to him, objects on the other side of the earth would fall towards him.

→ Thus gravitation is removable locally, but centrifugal force can be removed everywhere. The fallacy of this argument is that it speaks as though gravitation and centrifugal force were distinguishable experimentally.

→ The non rotating observer claim that he has got rid of all the ~~unused~~ central part, leaving a remainder (the usual gravitational field) which he regard as really existing.

→ It is not denied that the separation of centrifugal and gravitational force generally adopted has many advantages for mathematical calculation.

→ It often happens that the separation of a mathematical expression into two terms of distinct nature, though useful for elementary work, becomes vitiated for more accurate work by the occurrence of minute cross-terms which have to be taken into account.

→ Newtonian Mechanics proceed on the supposition that there is some super-observer. If he feels a field of force, then that force really exists.

→ But they are the victims of illusion.

→ Truant, or at least the misfit.

→ Newtonian Mechanics an artificial distinction is drawn between their circumstances; B is in no field of force at all, but A is really in a field of force, only its effects are neutralised by his acceleration. But what is this acceleration of A? Primarily it is an acceleration relative to the earth; but then that can equally well be described as an acceleration of the earth relative to A, and it is not fair to regard it as something located with A. Its importance in Newtonian

Philosophy is that it is an acceleration relative to what we have called the super-observer.

→ There would be a gravitational field, but the consequent acceleration of the observer and his landmarks would produce a field of force annulling it.

→ This field is not absolute, but always requires that some observer should be specified.

→ That there are certain intricacies in the gravitational influence radiating from heavy matter which are distinctive.

→ Uniform motion in a straight line is not the same for an observer rotating with the earth as for a non-rotating observer who takes into account the sinuosity of the rotation.

→ A straight-line in space-time is accordingly not an absolute conception, but is only defined relative to some observer.

→ Now we have seen that so long as the observer and his measuring appliances are unconstrained (falling freely) the field of force immediately round him vanishes. It is only when he is deflected from his proper track that he finds himself in the midst of a field of force.

→ A body does not leave its natural track without visible cause.

→ Our attention is thus directed to the natural tracks of unconstrained bodies, which appear to be marked out in some absolute way in the 4-D world.

Dg 6-3

→ Different observers will ~~observe~~ describe the track as straight, parabolical, or sinuous, but it is the same absolute locus.

→ Pretend to predict without reference to experiment the laws determining the nature of these tracks; but we examine whether our knowledge of the 4-D world is already sufficient to specify definite tracks of this kind, or whether it will be necessary to introduce new hypothetical factors.

→ The interval-length along a particular track is thus something which can be measured absolutely, since all observers agree as to the measurement of the interval for each subdivision, it follows that all observers will agree as to which track (if any) is the shortest track between the two points, judged in terms of interval-length.

→ It is not the shortest track, but the longest track, which is unique. There are many tracks of zero interval length, but there is just one which has maximum length. This is because of the peculiar geometry which the minus sign of $(t_2-t_1)^2$ introduces.

$$(x_2-x_1)^2 + (y_2-y_1)^2 + (z_2-z_1)^2 = (t_2-t_1)^2$$

→ When the resultant distance travelled in space is equal to the distance travelled in time, then s is zero. This happens when the velocity is unity - the velocity of light.

→ On the other hand there is evidently an upper limit to the interval-length of the track, because each portion of s is always less than the corresponding portion of (t_2-t_1), and s can never exceed t_2-t_1.

→ It is the time as perceived by an observer, or measured by a clock carried on the particle. This is called the proper-time; and, of course, it will not in general agree with the time-reckoning of the independent onlooker who is supposed to be watching the whole proceedings.

→ The condition $x_2 = x_1$, etc. means that the particle must remain stationary relative to the observer who is measuring x, y, z, t. To secure this we mount an observer on the particle, and then the interval-length 's' will be $t_2 - t_1$, which is the time elapsed according to his clock.

→ The term is not very logical unless the track in question is a natural track.

→ So that no clock could follow the track without violating the laws of nature. We may force it into the track by continually hitting it; but that treatment may not be good for its time keeping qualities.

Natural law
→ Every particle moves so as to take the track of greatest interval-length between two events, except in so far as it is disturbed by impacts of other particles or electrical forces.

→ We reserve only direct material impacts and electromagnetic causes, the latter being outside our present field of discussion.

→ In the weird geometry of the part of space-time through which it passes this longest track is a spiral a circle in space, drawn out into a spiral of by continuous displacement in time. Any other course would have had shorter interval-length.

→ The field of force is completely described if the tracks through space and time of particles projected in every possible way are prescribed.

→ To express this unmanageable mass of detail in a unified way a world-geometry is found in which the tracks of greatest length are the actual tracks of the particles.

→ The change from a mechanical to a geometrical theory of fields of force is not so fundamental a change as might be supposed.

→ We have to remember that natural geometry is equally a branch of mechanics, since it is concerned with the behaviour of material measuring-appliances.

→ There is no help for it, if the longest track can be a spiral like that known to be described by the earth.

→ In Euclidean geometry the shortest track is always a straight line; and the slight modification of Euclidean geometry described in Chapter-3 is found to give a straight line as the longest track.

→ But the point arises that the geometry arrived at in Chap-3 was not arbitrary. It was the synthesis of measures made with clocks and scales by observers with all kinds of uniform motion relative to one another; we cannot modify it arbitrarily to fit the behaviour of moving particles like the earth.

→ Geometry based on the natural tracks of moving particles.

→ Now it turns out that the free Motion of a particle is a much more sensitive way of exploring space-time, than any practicable measures with scales and clocks. If then we employ our accurate knowledge of the Motion of particles to correct the formula, we shall find that the changes introduced are so small that they are inappreciable in any practical measures with scales and clocks.

→ This refers to the behaviour of a clock on the surface of the Sun, but the experiment is one of great difficulty and no conclusive answer has been given.

→ The geometry of space and time based on the Motions of particles is accordant with the geometry based on the cruder observations with clocks and scales; but if subsequent experiment should reveal a discrepancy, we shall adhere to the moving particle on account of its greater simplicity.

→ But uniform Motion means that their 4-D tracks are straight lines. We must suppose that the observers were moving in their natural tracks; for, if not, they experienced fields of force and presumably allowed for these in their calculations, so that reduction was made to the natural tracks.

→ Suppose there is a region of space-time where for some observer the natural tracks are all straight lines and eqn is holds rigorously. For another (accelerated) observer, the track will be curved, and the equations will not hold. At the best, it is of a form which can only hold good for arbitrarily selected observers.

→ To throw our formula into the melting-pot.

→ When there is no force, the tracks of all particles are straight lines as our previous geometry requires. In any small region we can choose an observer (falling freely) for whom the force vanishes, and accordingly the original formula holds good. Thus it is only necessary to modify our rule for determining the interval by two provisos: (1) that the interval measured must be small, (2) that the scales and clocks used for measuring it must be falling freely.

→ The condition that the measuring appliances must not be subjected to a field of force.

→ Each portion of a radius is moving transversely and would therefore have no longitudinal contraction.

→ The point which the argument has overlooked is that the results here appealed to apply to unconstrained bodies, which have no acceleration relative to the natural tracks in space.

→ When accelerations as well as velocities occur a more far-reaching theory is needed to determine the changes of length.

→ The track between two (distant) events which has the largest interval-length must therefore have an absolute significance. Such tracks are called geodesics. Geodesics can be traced practically, because they are the tracks of particles undisturbed by material impacts. By the practical tracing of these geodesics we have the best means of studying the character of the natural geometry of the world.

→ We have said that no experiments have been able to detect a difference between a gravitational field and an artificial field of force such as the centrifugal force.

→ Principle of equivalence:-
A gravitational field of force is precisely equivalent to an artificial field of force, so that in any small region it is impossible by any conceivable experiment to distinguish between them.

→ In other words force is purely relative.

Kinds of force

→ For this reason, If we used a Mesh - system, it is Important to find formulae containing connecting the absolute distance with the particular system that is being used.

* For oblique coordinates (ξ, η),

$$ds^2 = d\xi^2 - 2k\,d\xi\,d\eta + d\eta^2$$

where, k is the cosine of the angle between the lines of partition.

→ For latitudes and longitude (β, λ)

$$ds^2 = d\beta^2 + \cos^2\beta\, d\lambda^2.$$

→ In order not to give away the secret permanently, it will be better to use the symbols.

→ The statement that polar co-ordinates are being used is unnecessary, because it ~~holds~~ adds nothing to our knowledge which is not already contained in the formula.

→ The name calls to our minds a number of familiar properties which otherwise might not occur to us.

→ It is found that all possible mesh-systems lead to values of ds^2, which can be included in an expression of this general form; so that mesh-systems are distinguished by three functions of position g_{11}, g_{12}, g_{22}, which can be determined by making physical measurements.

→ But the nature of our two dimensional space, which is independent of any mesh-system,

→ Try how you will, you cannot.

→ The g_{11}, g_{12}, g_{22} satisfy in all three cases, a certain differential equation.

→ It is annoying not to be able to express the differences of space in a purer form, without mixing them up with irrelevant differences of potential.

→ All physical knowledge is relative to space and time partitions; and to gain an understanding of the absolute, it is necessary to approach it through the relative. The absolute may be defined as a relative, which is always the same no matter what it is relative to.

→ Distance must be replaced by interval which it will be remembered, is an absolute quantity, and therefore independent of the mesh-system used, partitioning space-time by any system of meshes.

→ These are called the "Galilean Values." If the potentials have these values everywhere, space-time may be called "flat", because the geometry is that of a plane surface drawn in Euclidean space of five dimensions.

1→ The only way of discovering what kind of space-time is being dealt with is from the values of the potentials, which are determined practically by measurements of intervals.

2→ Different values of the potentials do not necessarily indicate different kinds of space-time.

3→ There is some complicated mathematical property, common to all values of the potentials which belong to the same space-time, which is not shared by those which belong to a different kind of space-time. This property is expressed by a set of differential equations.

→ For that geometry, the geodesics, giving the natural tracks of particles, are straight lines.

→ Thus in flat space-time the law of motion is that every particle moves uniformly in a straight line except when it is disturbed by the impacts of other particles. Clearly, this is not true of our world; for example, the planets do not move in straight lines, although they do not suffer any impacts.

→ It needs a large region to bring out the differences of geometry.

→ We cannot expect to tell whether a surface is flat or curved unless we consider a reasonably large portion of it.

→ According to Newtonian ideas, at a great distance from all matter beyond the reach of any gravitation, particles would all move uniformly in straight lines. Thus, at a great distance from all matter space-time tends to become perfectly flat.

→ Although near matter it is curved, it is this puckering near } matter which accounts for the gravitational effects.

→ It is like the notion of a field of force acting in space and time, merely introduced to bolster up Euclidean geometry, when Euclidean geometry has been found inappropriate.

→ Because the surfaces are differently curved in a real Euclidean space of five dimensions.

→ Space of five dimension is Euclidean; and presumably the answer would be because it is a plane in a real Euclidean space of six dimensions, and so on ad infinitum.

→ technical terms like differential invariant.

→ Because analogies based on three-dimensional space do not always apply immediately to many dimensional space.

→ A 4-D space with "no curvature" is not the same as a "flat" space! Three-dimensional geometry does not prepare us for these surprises.

→ Picturing the space-time in the gravitational field round the earth as a pucker, we notice that we cannot locate the pucker at a point; it is "somewhere round" the point.

→ What determines the existence of the pucker...

→ It is the way these values link on to those at other points, i.e., gradient of the g's and more, particularly the gradient of the gradient.

→ The kind of space-time is fixed by differential equations.

→ Nevertheless the presence of a heavy particle does modify the world around it, in an absolute way which cannot be imitated artificially. Gravitational force is relative, but there is this more cautious character of gravitational influence which is absolute.

→ Mathematically possible space-time. But to could that kind of space-time actually occur by any arrangement of the matter round the region?

→ The law which determines what kinds (space-time) can occur is the law of gravitation

→ Since we have reduced the theory of fields of force to a theory of the geometry of the world, that law must be of the nature of a restriction on the possible geometries of the world.

→ The choice of g's in any special problem is thus arrived at by a three-fold working out:-
1) Many sets of values can be dismissed because they can never occur in nature.
2) Others, while possible, do not relate to the kind of space-time present in the problem considered.
3) Of those which remain, one set of values relate to the particular mesh-system that has been chosen.

→ What is the criterion that decides what values of the g's give a kind of space-time possible in nature?

(4) Since it is a question of whether the kind of space-time is possible, the criterion must refer to those properties of the g's which distinguish different kinds of space-time, not to those which distinguish different kinds of Mesh-system in the same space-time. The formulae must therefore not be altered in any way, if we change the Mesh-system.

(5) We know that flat space-time can occur in nature. Hence the criterion must be satisfied by any values of the g's belonging to flat space-time.

→ Afterwards the further test must be applied whether the law is confirmed by observation.

→ Must be independent of any possible circumstances of the observers, namely a complete coincidence in space and time.

→ The standpoint of the observer is not involved.

→ Our knowledge of nature is a knowledge of intersections of world-lines, it is absolute knowledge independent of the observer.

→ We find that at least in all exact measurements, our knowledge is primarily built up of intersections of world-lines of two or more entities, that is to say their coincidences.

→ The actual observations was a coincidence of the image of a wire in the galvanometer with division of a scale.

→ The Condition for flat space-time which is generally written in the simpler, but not very 'Illuminating', form

$$B^{\rho}_{\mu\nu\sigma} = 0, \quad \text{—} (*)$$

→ There are 4^4 256 of these eqⁿ altogether, but many of them are repetitions. Only 20 of the equations are really necessary, the others merely say the same thing over again.

→ eqⁿ (*) is not the law of nature. If it were a law of nature, then only flat space-time could exist in nature, and there would be no such thing as gravitation. It is not the general condition, but a special case - when all attracting matter is infinitely remote.

→ What would it do to select a certain number of the 20 eqⁿs to be satisfied generally, leaving the rest to be satisfied only in the special case?

→ Then $G_{\mu\nu} = 0 \longrightarrow (*)$
will satisfy our requirements for a general law of nature.

→ So, when flat space-time occurs, this law of nature is not violated. Further it is not so stringent as the conditions for flatness, and admits of the occurrence of a limited variety of non-euclidean geometries.
Rejecting duplicates, it comprises 10 equations; but four of these can be derived from the other six, so that it gives six conditions, which happens to be the number required for a law of gravitation?

Consequences

→ GTR not only explains the motion of stars correctly but also the field of force experienced by himself.

→ $G_{\mu\nu} = 0$. It must in ordinary cases reduce to something so near the Newtonian law, that the remarkable confirmation of the latter by observation is accounted for.

→ Whether there are any exceptional cases in which the difference between it and Newton's law can be tested.

→ Something causing force in nature not comprised in the geometrical scheme hitherto considered, so that force is not purely relative, and Newton's super-observer exists.

→ It has to be remarked that in two dimensions there are gradations intermediate between a flat surface and a fully curved surface, which we shall speak of as curved in the first degree or second degree.

→ The full "curvature" of a surface is a single quantity called G, built up out of the various terms $G_{\mu\nu}$ in somewhat the same way as these are built up out of B^{ρ}, $B^{\rho}_{\mu\nu\sigma}$. The following conditions can be stated.

* If $B^{\rho}_{\mu\nu\sigma} = 0$ → (20 Conditions)

Space-time is flat. This is the state of the world at an infinite distance from all matter and all forms of energy.

* If $G_{\mu\nu} = 0$ → (6 Condition)

Space-time is curved in the first degree. This is the state of the world in an empty region not containing matter, light or E.M. fields, but in the neighbourhood of these forms of energy.

→ If $G_{\mu\nu} = 0$ → (1 Condition)
Spacetime is curved in the second degree. (This is the state of the world in a region not containing Matter or electrons (bound energy), but containing light or E.M. fields (free energy).

→ If $G_{\mu\nu}$ is not zero,
Space-time is fully curved. This is the state of the world in a region containing Continuous Matter.

→ (Theory Continuous Matter does not exist, so that strictly speaking the last case never arises.
The regions lying between the electrons are not fully curved, whilst the regions inside the electrons must be cut out of space-time altogether.

→ We need to know, not the actual values of the $g_{\mu\nu}$ at a point, but their average values through a region small from the ordinary standpoint but large compared with the Molecular structure of Matter. In this Macroscopic treatment Molecular Matter is replaced by Continuous Matter, and uncurved space-time ~~studded~~ stud-ded with holes is replaced by an equivalent fully curved space-time without holes.

→ Matter and energy, not as agents causing the degrees of curvature of the world, but as parts of our perceptions of the existence of the curvature.

→ In an empty region, space-time can be curved only in the first degree,

The New Law of Gravitation.

→ great ocean of truth a lay all undiscovered before me

→ Certain & unexplained irregularities in the Moon's Motion,

→ This was the discordance of Motion of the perihelion of Mercury. How small was this discrepancy may be judged from the fact that to meet it, it was proposed to amend square of the distance to the 2.000 000 16 power of the distance. That the Matter causing the Zodiacal light might be of Sufficient mass to be responsible for this effect.

→ The law refers to the product of the Masses of the two bodies; but the mass depends on the velocity - a fact unknown in Newton's day. Are we to take the variable Mass, or the mass reduced to rest?

→ Distance also referred to in the law, is something relative to an observer. Until comparatively recently it was thought that conclusive proof had been given that the speed of gravitation must be far higher than that of light.

→ disagreeing with observation of the speed is at all comparable with that of light.
Electric influences being propagated with the velocity of light.

→ But what has the degree of curvature of space-time to do with attractive forces, whether real or apparent.

→ Concentrated attention on the curves rather than on the forces.

→ If a traveller goes over the left slope of a Mountain, he must consciously keep bearing away to the left if he wishes to keep to his original direction relative to the point of conflow. This was the secret of the Mysterious attraction, or bending of the paths, which was experienced in the region.

→ In the form $G_{\mu\nu} = 0$ Einstein's law expresses condition to be satisfied in a gravitational field produced by any arbitrary distribution of attracting matter. An analogous form of Newton's law was given by Laplace in his celebrated expression $\nabla^2 V = 0$.

→ We ask what kind of space-time exists in the region round a single attracting particle?
The sixth remaining dimension of space can always be added if desired by the conditions of symmetry. The result of long algebraic calculations is that round a particle

$$ds^2 = -\frac{1}{\gamma} dr^2 - r^2 d\theta^2 + \gamma dt^2$$

where $\gamma = 1 - \frac{2M}{r}$.

→ The fact is that this expression for ds^2 is found in the first place simply as a particular solution of Einstein's Equations of the gravitational field: it is a variety of hummock which is not curved beyond the first degree

→ We have to trace some of the consequences, find out how any particular particle moves when ds^2 is of this form, and then examine whether we know of any case in which these consequences, find out how any particles moves when ds^2 is of this form, and then examine whether we know of any case in which there

Whether we know of any case in which these conditions are found observationally. It is only after having ascertained that this form, and then examine, whether of ds^2 does correspond to the leading observed effects attributable to a particular of Mass at the origin that we have the right to identify this particular solution with the one we hoped to find.

→ If we indicate how the position of Matter causing this particular solution is located. Whether wherever our formula (1) holds good there can be no Matter, because the law which applies to empty space is satisfied. But if we try to approach the origin ($r=0$) a curious thing happens.

→ Keeping the time 't' constant, and $d\theta$ being zero for radial measurements, the formula (1) reduces to,

$$ds^2 = -1/\gamma \, dr^2$$

$$\text{or} \quad dr^2 = -\gamma \, ds^2$$

→ We start with r large. By and by we approach the point where $r=2M$. But here from its definition γ is equal to 0. So that however large the measured interval ds may be, $dr = 0$.

→ But dr is zero; that is to say, we do not reduce r.

→ By that a particle of Matter is filled up to the interior.

→ We have to place true limited only in the first degree. We are never round of the outside.

$2M/r$.

It must end in an infinite chimney. In place of chimney, however we round it off with a small region of greater curvature.

→ We describe it therefore as containing matter.

→ If any question arises as to the exact significance of r and t, it must always be settled by reference to eq. 6).

→ The want of flatness in the gravitational field is indicated by the deviation of the coefficient γ from unity. If the mass $M = 0$, $\gamma = 1$, and space-time is perfectly flat. Even in the most intense gravitational fields known, the deviation is extremely small. For the sun, the quantity M, called the gravitational mass, is only 1.47 km, for the earth, it is 5 mm. In any practical problem the ratio $2M/r$ must be exceedingly small. Yet it is on the small corresponding difference in γ that the whole of the phenomena of gravitation depend.

→ The coefficient γ appears twice in the formula, and so modifies the flatness of space-time in two ways.

→ Its appearance as a coefficient of dt^2 produces much of the most striking effects. Suppose that it is wished to measure the interval between two events in the history of the planet.

If the events are, say 1 sec. apart in time; $dt = 1$ sec $= 300,000$ km.

Thus, $dt^2 = 90,000,000,000$ sq. km.

Now no planet moves more than 50 km in a second, so that the change dr associated with the lapse of 1 sec. in the history of the planet will not be more than 50 km.

Thus dr^2 is not more than 2510 sq. km. Evidently the small term $2m/r$ has a much greater chance of making an impression where it is multiplied by dt^2 than where it is multiplied by dr^2.

→ We ignore the coefficient of dr^2

Mean $$ds^2 = -dr^2 - r^2 d\theta^2 + (1 - 2m/r)\, dt^2$$

Particles situated in this kind of space time will appear to be under the influence of an attractive force directed towards the origin.

→ In 4-D interval is the analogue of distance and a map of 4-D world will aim at showing all the intervals in their correct proportions. Our natural picture of space-time takes r and t as horizontal and vertical distances.

→ The r and t lines run obliquely or in curves across the map.

→ The factor $1-2m/r$ decreases towards the left where r is small, and consequently any change of t corresponds to a shorter interval and must be represented in the map by a shorter distance on the left. It is con easy to see why the r-lines take the course shown; by analogy with latitude and longitude we might expect them to be curved the other way.

→ Now the slope of the time-direction is connected with the slope of the space-direction.

→ These are not the result of any precise measures with scales and clocks made at a point, but are mathematical variables most appropriate for describing the whole solar system. They represent a compromise, because it is necessary to deal with a region too large for accurate representation on a plane map.

→ Because it does not represent in their true proportions the intervals between the various points in the picture. It is not possible to draw any map of the whole curved region without distortion but a small enough portion can be represented without distortion if the partition of equal r and t are drawn.

→ The substitution $x = r + \frac{1}{2}t^2 M/r^2$,

$$y = t(1 - M/r), \text{ gives } ds^2 = -dx^2 + dy^2$$

If squares of M are negligible.

→ In each successive vertical interval (time) a successively greater progress is made to the left horizontally (r decr). Thus the velocity towards the sun increases. We say that the particle is attracted to the sun,

→ For a particle with small velocity the acceleration towards the sun is approximately M/r^2, agreeing with the Newtonian law.

→ Whilst becoming more nearly vertical it receives a curvature, in the opposite direction. The effect of the gravitation of the sun on a light-wave, or very fast particle, proceeding radially is actually a repulsion.

→ The track of the transverse light wave, coming out from the plane of the paper, will be affected like that of a particle of zero velocity in distorting frame __. Hence the sun's influence on a transverse light wave is always an attraction. The acceleration is simply M/r^2, as for a particle at rest.

→ It shows that the law $G_{\mu\nu} = 0$, proposed on theoretical grounds agrees with observation at least approximately.

→ All planetary speeds are small compared with velocity of light, and the considerations mentioned at the beginning of this chapter suggest that some modification may be needed for speeds comparable with that of light.

→ The attraction of gravitation is simply a geometrical deformation of the straight tracks.

→ The deformation is a general discrepancy between the "Mental Picture" and the "true Map" of the portion of space-time considered.

→ Otherwise we could distinguish between the acceleration of a lift, and a true increase of gravitation by optical instruments, in that case the observer for whom light-rays appear to take straight tracks might ~~be~~ be described as absolutely unaccelerated and there could be no relativity theory.

→ An influence of gravitation on light similar to that exerted on matter; and the problem whether or not light has "weight" has often been considered.

→ The appearance of γ as the coefficient of dt^2 is responsible for the main features of Newtonian Gravitation; the appearance of $1/\gamma$ as the coefficient of dr^2 is responsible for the predicted observational deviations of the new law from the old.

We consider the space-terms alone,

$$ds^2 = \frac{1}{\gamma} dr^2 + r^2 d\theta^2.$$

The expression shows that space considered alone is non-Euclidean in the neighbourhood of an attracting particle.
This is something entirely outside the scope of the old law of gravitation. Time can only be explored by something moving, whether a free particle or the parts of a clock, so that non-Euclidean character of space-time can be covered up by introducing a field of force, suitably modifying the motion, as a convenient fiction.

→ And theoretically the non-Euclidean character could be ascertained by sufficiently precise measures with rigid scales.

→ If we lay our measuring scale transversely and proceed to measure the circumference of circles of nominal radius 'r', we see from the formula that the measured length ds is equal to $r\,d\theta$, so that, when we have gone right round the circle, θ has increased by 2π and the measured circumference is $2\pi r$.
But when we lay the scale radially the measured length $2\pi r$. But when we lay the scale radially the measured length ds is equal to $dr/\sqrt{\gamma}$, which is always greater than dr, each portion being greater

than the corresponding change of r.

→ Placing the particle near, instead of at, the centre, avoids measuring the diameter through the particle, and so make the experiment a practical one.

→ If the mass of a ton were placed inside a circle of 5 yards radius, the defect in the value of π would only appear in the twenty-fourth or twenty-fifth place of decimals.

(we change the sign of ds^2; so that ds, when real, means measured space instead of measured time)

→ This has the advantage that if an earthquake occurs, deforming the field, the map will still be correct.

→ but we could gain nothing by taking a straighter course. Since that would lead through a region where the hurdles are more crowded.

→ Fig. 14. The straight line PQ represents the path of fewest hurdles from P to Q, and its length is proportional to the number of hurdles. Fig 15. represents the distorted field, with PQ distorted into a curve; but PQ is still the path of fewest hurdles from P to Q, and the number of hurdles in the path is the same as before.

→ And clearly it must be a curve such that the minimum number of hurdles between any point on it and the centre is a constant (the radius). With this definition we can defy earthquakes.

→ Thus we have a suitable analogy for a circle whose

Whose ~~diameter~~ circumference is less than π times its diameter.

→ The particle track will thus be a little concave to the centre, and an onlooker will say that it has been attracted to the centre. It is rather curious that we should call it attraction when the track has rather been avoiding the central region; but it is clear that the direction of motion has been bent round in the way attributable to an attractive force.

→ This bending of the path is additional to that due to Newtonian force of gravitation which depends on the second appearance of r in the formula. As already explained it is in general a far smaller effect and will appear only as a minute correction to Newton's laws.

→ The only case where the two rise to equal importance is when the track is that of a light-wave, or of a particle moving with a speed approaching that of light; for then dr^2 rises to the same order of magnitude as dt^2.

→ A ray of light passing near a heavy particle will be bent, firstly, owing to non-Euclidean character of the combination of time with space; this bending is equivalent to that due to Newtonian gravitation, and may be calculated in the ordinary way on the assumption that light has weight like material body. Secondly, it will be bent owing to the non-Euclidean character of space alone, and this curvature is additional to that predicted by Newton's law. If then, we can observe the amount of curvature of a ray of light, we can make a crucial test of whether Einstein's or Newton's theory is obeyed.

→ The path of fewest hurdles is the only track capable of absolute definition.

→ Both causes of bending may be ascribed either to weight or to non-Euclidean space-time, according to the nomenclature preferred. The only difference between the predictions of the old and new theories is that in one case the weight is calculated according to Newton's law of gravitation, in the other case according to Einstein's.

→ This depends on the fact that the velocity of light in gravitational field is not a constant (unity) but becomes smaller as we approach the ~~sun~~ sun.

→ It is the coordinate velocity that is here referred to, described in terms of the quantities r, θ, t introduced by the observer who is contemplating the whole solar system at the same time.

Pg-59

→ Analytically the distinction is that for the interval OP, ds^2 is positive, for OP', ds^2 is negative. In the first case, the interval is real or "time-like", in the second it is imaginary or "space-like". The two regions are separated by lines (or strictly, cones), in crossing which ds^2 changes from positive to negative; and along the lines themselves ds is zero.

→ Physically their most important property is that pulses of light travel along these tracks, and the motion of a light-pulse is always given by the equation $ds = 0$

→ Using the expression for ds^2 in a gravitational field, we accordingly have for light,

$$0 = -\frac{1}{\gamma} dr^2 - r^2 d\theta^2 + \gamma\, dt^2$$

For radial motion, $d\theta = 0$, and therefore

$$\left(\frac{dr}{dt}\right)^2 = \gamma^2.$$

For transverse motion $dr = 0$, and therefore

$$\left(\frac{r\,d\theta}{dt}\right)^2 = \gamma$$

Thus the coordinate velocity of light travelling radially is γ, and of light travelling transversely is $\sqrt{\gamma}$, in the co-ordinates chosen,

→ The coordinate velocity must depend on the coordinates chosen, and it is more convenient to use a slightly different system in which the velocity of light is the same in all directions* viz. $\sqrt{\gamma}$ or $1 - 2M/r$.

→ A pulse of light proceeding radially is repelled by the sun,

→ In the same way when the light waves pass near the sun, the end nearest the sun has the smaller velocity, and the wave-front slews round; thus the course of the waves is bent.

→ The velocity being inversely proportional to the refractive index of the medium. The phenomenon of refraction is in fact caused by a slewing of the wave-front in passing into a region of smaller velocity. We can thus imitate the gravitational effect on light precisely, if we imagine the space around the sun filled with a refracting medium which gives the appropriate velocity for light. To give the velocity $1-2M/r$, the refractive index must be $1/(1-2M/r)$, or, very approximately, $1+\frac{2M}{r}$. At the surface of the sun, $r = 697,000$ km, $M = 1.47$ km, hence the necessary refractive index is 1.00000424. At a height above the sun equal to the radius it is 1.00000212.

→ This is obtained by writing $r+M$ instead of r, or diminishing the nominal distance of the sun by $1\frac{1}{2}$ km.

This change of co-ordinates simplifies the problem, but course can, of course, make no difference to anything observable. After we have traced the course of the light ray in the co-ordinates chosen, we have to connect the results with experimental measures using the corresponding formula for ds^2.

→ Because it relates to measuring operations performed in a terrestrial observatory where the difference of γ from unity is negligible.

→ Any problem on the paths of rays near the sun can now be solved by the methods of geometrical optics applied to the equivalent refracting medium.

→ It is not difficult to show that the total deflection of a ray of light passing at a distance r from the centre of the sun is $4M/r$, whereas the deflection of the same ray calculated in Newtonian theory would be $2M/r$.

Chap-7

Weighing light

→ Experimental test of Influence of gravitation on light

→ Whether light has weight (as suggested by Newton) or it is indifferent to gravitation; Secondly, if it has weight, is the amount of the deflection in accordance with Einstein's or Newton's law?

→ Light possesses Mass or Inertia. This is Manifested in the phenomena of radiation-pressure.

→ This Inertia of radiation is of great cosmical importance, playing a great part in the equilibrium of the more diffuse stars.

→ Possibly the tails of comets are a witness to the power of the Momentum of sunlight, which drives outwards the smaller or the more absorptive particles.

→ All the sunlight falling on the earth amounts to 160 tons daily.

→ Not easy to realise how a wave-motion can have Inertia, and it is still more difficult to understand what is meant by it's having weight.

→ It is not difficult to deduce the effects of this weight on a freely Moving light-beam not enclosed within a hollow.

→ The effect of weight is that the radiation in the hollow body acquires each second of a downward momentum proportional to it's Mass. For a free light-wave in space the added Momentum Combines with the original Momentum, and the total Momentum determines the direction of the ray, which is accordingly bent.

→ Einstein's theory provides a Means viz. the variation of velocity of the waves.

→ One very important fact had already shown that this proportionality is not confined to Material energy.

→ The energy of radio-activity has weight.

→ Not justified in deducing the properties of the free energy of light.

→ If the mass and weight of light are in the same proportion as for the Matter, the ray of light will be bent just like the trajectory of a Material particle.

→ Since it has travelled 186,000 miles along its course in that time, the bend is inappreciable. In fact any terrestrial course is described so quickly that gravitation has scarcely had time to accomplish anything.

→ There we get a pull of gravitation 27 times more intense than on the earth, and what is more important - the greater size of the sun permits a much larger trajectory throughout which the gravitation is reasonably powerful. The deflection, in this case may amount to something of the order of a second of arc which for the astronomer is a fairly large quantity.

→ Since the light rays enter the observer's eye or telescope in the direction FE, this will be the direction in which the star appears. But it's true direction FE, this will be the direction in which the stars appear. But its true direction from the earth is QP, the initial course. So the star appears displaced outwards from its true position by an angle equal to the total deflection of light.

→ It must be noticed that this is only true because a star is so remote that its true direction from the earth is OP, the initial course, with respect to the earth. O is indistinguishable from its direction with respect to the point Q.

→ For a source of light within the solar system, the apparent displacement of the source is by no means equal to the deflection of the light-ray.

→ Making a observation is during a total eclipse when the moon cuts off the dazzling light.

→ It is thus necessary to have rather brighter stars near the sun, which will not be lost in the glare of the corona. Further, the displacements of these stars can only be measured relatively to other stars, preferably more distant from the sun and less displaced; we need therefore, a reasonable number of outer bright stars to serve as reference points.

→ Most favourable day of the year for weighing light is May 29. The reason is that the sun in its annual journey round the ecliptic goes through fields of stars of varying richness, but on May 29, it is in the midst of a quite exceptional patch of bright stars, part of the Hyades, by far the best star-field encountered.

→ It is not suggested that it is impossible to make the test at other eclipses, but the work will necessarily be more [illegible].

→ The problem was to determine how the apparent positions of the stars, affected by the sun's gravitational field, compared with the normal positions on a photograph taken when the sun was out of the way.

→ In comparing two plates, various allowances have to be made for refraction, aberration, plate-orientation, etc.; but since these occur equally in determinations of stellar parallax, for which much greater accuracy is required, the necessary procedure is well-known to astronomers.

→ The results from this plate gave a definite displacement.

→ The use of this instrument must have presented considerable difficulties - the unwieldy length of the telescope, the slower speed of the lens necessitating longer exposures and more accurate driving of the clock-work, the larger scale rendering the focus more sensitive to disturbances but the observers achieved success, and the perfection of the negatives surpassed anything that could have been hoped for.

→ It will be remembered that Einstein's theory predicts deflection of 1''.74 at the edges of the sun, the amount falling off inversely as the distance from the sun's centre.

→ The evidence of the principe plates is thus just about sufficient to rule out the possibility of the "half-deflection", and the Sobral plates exclude it with practical certainty.

→ Theoretical deflection should vary inversely as the distance from the sun's centre.

→ The gravitational effect on light is equivalent to that produced by a refracting medium round the sun and have calculated the necessary refractive index.

→ If the irreconcilable critic insists that the material round the sun may be composed of some new element with properties unlike any material known to us, we may reply that the mechanism of refraction and of absorption is the same, and there is a limit to the possibility of refraction without appreciable absorption.

→ The density of the material falls off inversely as the distance from the sun's centre in order to give the required variation of refractive index.

→ A study of these comets sets an upper limit to the density of the corona, which makes the refractive effect quite negligible.

— The

Na - 8. Other Tests of Theory

→ The light rays & light rays however great advantage of a means of exploring the non-Euclidean property of space.

→ Newton's law a planet moves around the sun in an ellipse.

→ According to Einstein's law the path is very nearly an ellipse but it does not quite close up; and in the next revolution the path has advanced slightly in the same direction as that in which the planet was moving. The orbit is thus an ellipse which very slowly revolves.

→ The exact prediction of Einstein's law is that in one revolution of the planet the orbit will advance through a fraction of a revolution equal to $3v^2/c^2$ where c is the speed of light; thus in one revolution (one year), the point where the earth is at greatest distance from the sun will move on 3/100,000,000 of a revolution, or 0".038.

→ We can choose a planet with higher speed so that the effect is increased not only because v^2 is increased but because the revolutions take less time; but, what is perhaps more important, we need a planet with a sharp elliptical orbit, so that it is easy to observe how its apses move around.

→ Mercury - fastest of the planets, and predicted advance of the orbit amounts to 43" per century.

→ Any slight deviations from the Inverse Square law is likely to cause an advance or recession of the apse of the orbit. That a particle, if it does not move in a circle, should oscillate between two extreme distances is natural enough; it could scarcely do anything else unless it had sufficient speed to break away together.

→ It had already been recognised that the change of Mass with Velocity May cause an advance of perihelion; but owing to the ambiguity of Newton's law of gravitation, the discussion was unsatisfactory.

→ It was, however, clear that the effect was too small to account for the Motion of perihelion of Mercury, the prediction being $\frac{1}{4} v^2/c^2$, or at most v^2/c^2. Einstein's theory is the only one which gives the full amount $3v^2/c^2$.

→ Either the Sun's Motion through the aether is improbably small, or gravitation Must Conform to relativity in the sense of the restricted principle (P. 18), and Conceal the effect of the Increase of Mass with speed so far as an additive uniform Motion is Concerned.

→ Einstein's law of gravitation for fast Movement (light), and for Moderately slow Movement (Mercury).

→ Every particle or light-pulse moves so that the quantity s measured along its track between two points has the Maximum possible value, where,

$$ds^2 = -\left(1 - \frac{2M}{r}\right)^{-1} dr^2 - r^2 d\theta^2 + \left(1 - \frac{2M}{r}\right) dt^2$$

→ And the accuracy of the experimental test is sufficient to verify the coefficients as far as terms of order M/r in the coefficient of dr^2, and as far as terms of order M^2/r^2 in the coefficient of dt^2.

→ Space in the gravitational field of the sun is non-Euclidean or [illegible].

→ does not [illegible] [illegible] to draw any distinction between the warping of physical space and the warping of physical objects which define space.

→ Phenomena of the gravitational field as curiosities, it would, we [illegible] be preferable to avoid using words which are liable to misconstrued.

→ Whether the geometry of scales and clocks is the same as of the geometry of moving particles and light-pulses.

→ if the space and time of ordinary perception, may remain Euclidean.

→ The track of a light-wave in terms of the co-ordinates r, θ, and t cannot be tested directly; the co-ordinates afford only a temporary resting place; and the measurement of the displacement of the star-image on the photographic plates involves a reconversion from the co-ordinates to s, which [illegible] appears in its significance as the intervals in clock-scale geometry.

→ The interval must be determined by the nature of the atom; and hence atoms which are absolutely similar will measure by their vibrations equal values

of the absolute Interval ds.
Let us adopt the usual Mesh system (r, θ, t) for the polar system, so that

$$ds^2 = -\gamma^{-1} dr^2 - r^2 d\theta^2 + \gamma\, dt^2$$

→ If ds corresponds to one vibration, then, since the atom has not moved, the corresponding dr and dθ will be zero, and we have,

$$ds^2 = \gamma\, dt^2$$

The time of vibration dt is thus $1/\sqrt{\gamma}$ times the Interval of vibration ds.

» The Interval of vibration will be the same for both, but the time of vibration will be proportional to the Inverse square root of γ, which differs for the two atoms. Since.

$$\gamma = 1 - 2M/r.$$

$$\therefore \gamma = 1 - 2M/r$$

$$1/\sqrt{\gamma} = 1 + M/r, \text{ (very approx.)}$$

→ The first and second pulse have to travel the same distance (r), and they travel with the same velocity (dr/dt), for the velocity of light in the Mesh system used is $1 - 2M/r$, and though this velocity depends on r, it does not depend on t. Hence the difference dt at one end of the wave is the same as that at the other end.

→ Light from a solar source should be of greater period and greater wave-length (i.e. redder) than that form a corresponding terrestrial source.

→ Towards the red end of the spectrum.

→ Corresponding shift of the spectral lines occurs for an atom in a field of centrifugal force.
Suppose that as we rotate with the earth we observe very remote atom momentarily at rest relative to our rotating axes. This case is just analogous to that of the solar atom; both are at rest relative to the respective Earth-systems; the solar atom is in a field of gravitational force, and the other is in a field of centrifugal force.

→ Hence the atom in the centrifugal field ought also to vibrate more slowly, and show a displacement to the red of its spectral lines.

→ We can abolish the centrifugal force by choosing non-rotating axes.

→ The shift of spectral lines due to a field of centrifugal force is only another aspect of a phenomenon already discussed.

→ The only possible conclusion is that there are certain causes of displacements of the lines acting in the solar atmosphere and not yet identified.

→ We started with a definition of the interval by measurements made with clocks and scales and afterwards connected it with the tracks of moving particles.

→ The best course then is to discover do by exploration of space and time with a moving particle or light-pulse, rather than by measures with scales and clocks.

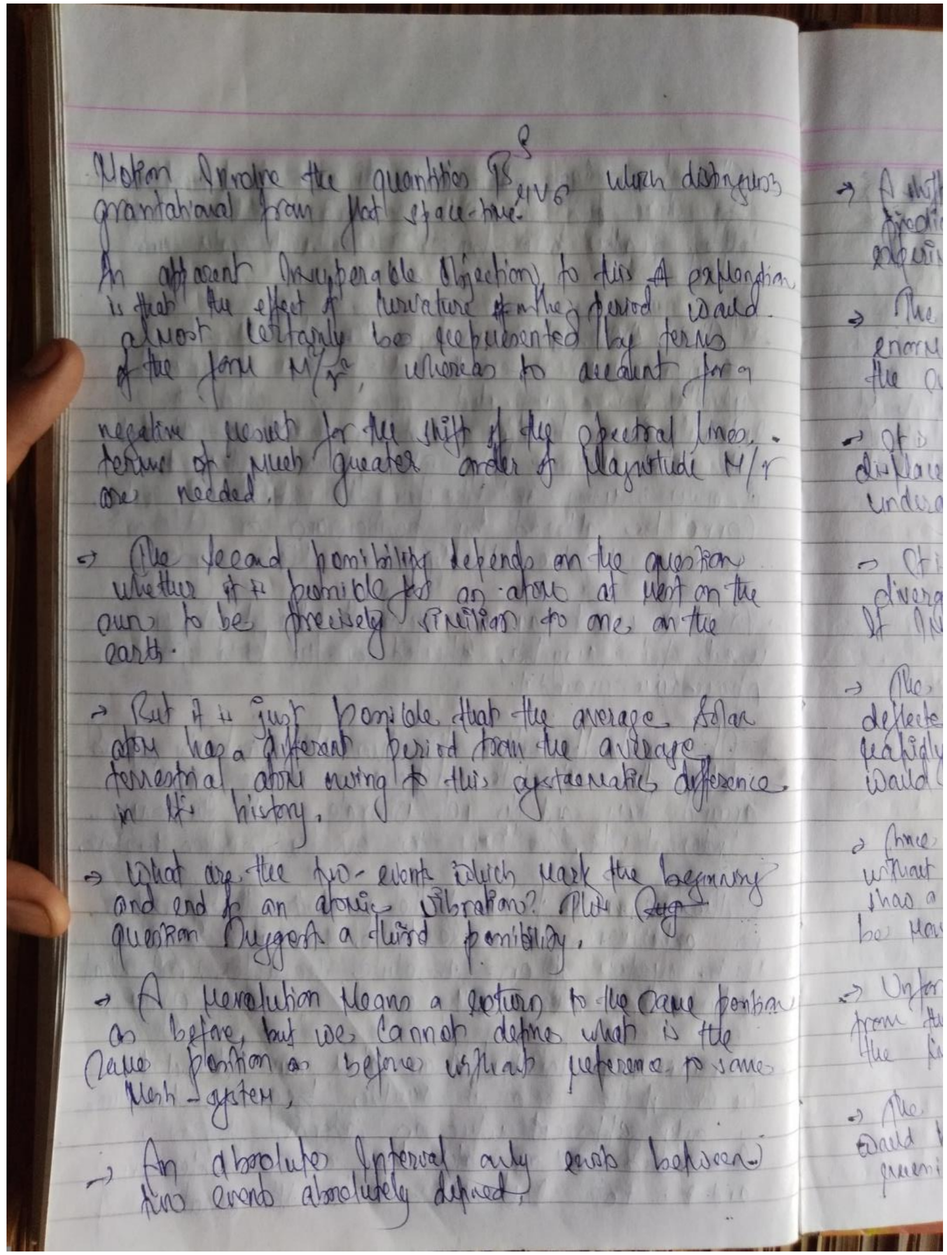
→ This short-cut is in fact the principle of equivalence. Whatever the mechanism of the clock, whether it is a good clock or a bad clock, the intervals it is beating must be something absolute; the clock cannot know what mesh-system the observer is using, and therefore its absolutely rate cannot be altered by position and or motion, which is relative merely to a mesh-system.

→ A clock cannot pay any heed to the mesh-system used, but it may be affected by the kind of space-time around it.

→ It may happen that the two atoms actually detect this absolute difference in the world around them and do not vibrate with the same interval ds, contrary to our assumption above.

→ The essential point of the relativity theory is that no experiments yet made have revealed any mesh-system of an absolute character, not that experiments never will reveal such a system.

→ Now it is very doubtful if an atom can detect the curving of the region it occupies, because curvature is only apparent when an extended region is considered. Still an atom has some extension, and it is not impossible that its equation of


Notion involve the quantities $g_{\mu\nu}$ which distinguish gravitational from flat space-time.

An apparent insuperable objection to this A explanation is that the effect of curvature on the period would almost certainly be represented by terms of the form M/r^2, whereas to account for a negative result for the shift of the spectral lines, terms of much greater order of magnitude M/r are needed.

→ The second possibility depends on the question whether it is possible for an atom at rest on the sun to be precisely similar to one on the earth.

→ But it is just possible that the average solar atom has a different period from the average terrestrial atom owing to this systematic difference in its history.

→ What are the two events which mark the beginning and end of an atomic vibration? [illegible] question suggest a third possibility.

→ A revolution means a return to the same position as before, but we cannot define what is the same position as before without reference to some mesh-system.

→ An absolute interval only exists between two events absolutely defined.

→ A shift of the Fraunhofer lines is a highly probable prediction from the theory and I anticipate that experiment will ultimately confirm the prediction.

→ The essential point in the argument was the enormous ratio of the distance QP of the star from the sun to the distance EF of the sun from the earth.

→ It is only in these conditions that the apparent displacement of the object is equal to the deflection undergone by the light.

→ It is easily calculated that the increased divergence would so weaken the light as to make it impossible to detect it when it reached us.

→ The course of the ray would not yet be appreciably deflected but the divergence of the pencil would be rapidly increased, and less light from the star would enter our telescopes.

→ Since certain stars are more massive than the sun, without the radius being unduly increased, they should show a greater shift of the spectral lines and might be more favourable for the third crucial test.

→ Unfortunately the predicted shift is indistinguishable from that caused by a velocity of recession in the line-of-sight on Doppler's principle.

→ The only indication that could be obtained there would be the detection of an average motion of recession of the more massive stars.

→ Actually the Most Massive stars have been found to show an average velocity of recession of 4.5 km. per sec. which would be explained if the values of Ψ/r for these stars are about 7 times greater than the value for the Sun a quite reasonable hypothesis.

→ Moreover, the very diffuse "giant" type stars of type M have also a considerable systematic velocity of recession, and for these Ψ/r must be much less than for the Sun.

Chap- 9 Momentum & Energy

→ Most Important Consequence of the relativity theory is the unification of Inertia and gravitation.

→ So that if all Interference by friction were removed uniform Motion might continue Indefinitely.

→ Gravitational force is not an active agent working against the passive tendency of Inertia. Gravitation and Inertia are one.

→ If there is anything that can be called an Innate tendency, it is the tendency to follow what we have called the natural track — the longest track between two points.

→ Whether the natural track is straight or curved, whether the Motion is uniform or changing, a Cause is in any case required. This cause is in all the cases the combined Inertia-gravitation.

→ The Identification of Inertia and gravitation as arbitrary components of one property explains why weight is always proportional to Inertia.

→ Einstein's law of gravitation gives the rule according to which the curvatures at any point of space-time link on to those at surrounding points; so that when a groove is started in any direction the rest of its course can be forecasted.

→ But the law of Einstein equally shows how the gravitational field spreads out in time, since there is no absolute distinction of time and space.

→ It can be deduced Mathematically from Newton's law that a pucker of the form corresponding to a particle necessarily runs along the track of greatest Interval-length between two points.

→ The track of a particle of Matter is thus determined by the Interaction of the Minute gravitational field, which surrounds and, so far as we know, constitutes it, with the general space-time of the region.

→ The application of Einstein's law to trace the gravitational field not only through space but through time leads to a great Unification of Mechanics.

→ Nothing is needed for this except the law of gravitation; that the curvature is only of the first degree — and there can thus be nothing in the predictions of Mechanics which is not comprised in the law of gravitation.
The conservation of Mass, of energy, and of Momentum Must all be contained implicitly in Einstein's law.

→ Because in many Mechanical problems gravitation in the ordinary sense can be neglected. But Inertia and gravitation are unified; the law is also the law of Inertia; and Inertia or Mass appears in all Mechanical problems.

→ We do not mean that the Interaction of the pucker of a particle with the general character of the space-time in which it lies can be neglected, because this constitutes the Inertia of the particle.

→ The Conservation of energy and Momentum must be deducible like everything else in Mechanics from the law of gravitation. It is a great triumph for Einstein's theory that his law gives correctly these experimental principles which have generally been regarded as unconnected with gravitation.

→ Although the values of $T_{\mu\nu}$ are strictly zero everywhere in space-time, yet if we take average values through a small region containing a large number of particles of Matter their average (or "Macroscopic") values will not be zero. It is the g's which are first averaged, then the $G_{\mu\nu}$ are calculated by the formulae.

→ Expressions for these Macroscopic values can be found in terms of the number, masses and motions of the particles. Since we have averaged the $G_{\mu\nu}$, we should also average the particles; that is to say, we replace them by a distribution of continuous Matter having equivalent properties. We thus obtain the Macroscopic equations of the form

$$G_{\mu\nu} = K_{\mu\nu}$$

Where on the one side we have the somewhat abstruse quantities describing the kind of space-time, and on the other side we have well-known physical quantities describing the density, momentum, energy, and internal stresses of the Matter present.

→ Poisson's eqn for Continuous Matter $\nabla^2\phi = -4\pi\rho$

→ When Continuous Matter is admitted, any kind of space-time becomes possible.

→ What values of $K_{\mu\nu}$, i.e. what distribution and motion of continuous matter, in the region, are a necessary concomitant accompaniment.

→ We have only to calculate, by the formulae the corresponding values of $G_{\mu\nu}$ and we at once obtain ten equations giving the $K_{\mu\nu}$, which defines the conditions of the matter necessary to produce these potentials.

→ The distribution must be mechanically possible, it might, however, be unrealisable in practice, involving inordinately high or even negative density of matter.

→ In connection with the law for empty space, $G_{\mu\nu}=0$, it was noticed that whereas this apparently forms a set of ten quantities, eqns, only six of them can be independent.

→ This was because ten equations would suffice to determine the ten potentials precisely, and so fix not only the kind of space-time but the mesh-system.

→ To allow for the four-fold arbitrariness of choice, there must be four relations always satisfied by the $G_{\mu\nu}$, so that when six of the equations are given the remaining four become tautological.

→ These relations must be identities implied in the mathematical definition of $G_{\mu\nu}$, that is to say, when the $G_{\mu\nu}$ have been written out in full according to their definition, and the operation

Indicated by the Identities carried out, all the terms will cancel, leaving only 0 = 0. The essential point is that the four relations follow from the mode of formation of the $G_{\mu\nu}$ from their simpler constituents ($g_{\mu\nu}$ and their differential coefficients), and apply universally.

→ When in continuous matter, $G_{\mu\nu} = K_{\mu\nu}$ clearly the same four relations must exist between the $K_{\mu\nu}$, not now as identities, but as consequences of the law of gravitation, viz. the equality of $G_{\mu\nu}$ and $K_{\mu\nu}$.

→ Thus the four dimensions of the world bring about a four fold arbitrariness of choice of mesh-system; this in turn, necessitates four identical relations between the $G_{\mu\nu}$ and finally, in consequence of the law of gravitation, these identities reveal four hard facts or laws relating to the density, energy, momentum or stress of matter summarised in the expression $K_{\mu\nu}$.

→ These four laws turn out to be the laws of conservation of momentum and energy.

→ Mass of the particle was a number attached to a particle, expressing an intrinsic property.

→ The discrepancy arises because in the construction the lines are prolonged to meet partitions which are different for two observers. Make the same construction, independent of their partitions, so that both arrive by the two routes at the same point C

→ Then if Momentum is conserved for one observer, it will be conserved for the other.

→ Momentum must now be the mass multiplied by the change of position δx per lapse of interval δs, instead of per lapse of time δt.

Thus. Momentum = $M \frac{\delta x}{\delta s}$

Instead of Momentum = $M \frac{\delta x}{dt}$.

and the mass M still preserves its character as an invariant number associated with the particle.

→ With regard to experimental confirmation it is sufficient at present to state that in all ordinary cases the interval and the time are so nearly equal that such experimental foundations as existed for the law of conservation of the old Momentum is just as applicable to the new Momentum.

→ Theory of relativity Momentum appears as an invariant mass multiplied by a modified velocity $\delta x/\delta s$.

we have $M \frac{\delta x}{\delta s} = M \frac{\delta t}{\delta s} \cdot \frac{\delta x}{\delta t}$.

accordingly the Momentum is separated into two factors, the velocity $\delta x/\delta t$ and a mass $M = M \frac{\delta t}{\delta s}$.

Which is no longer an invariant for the particle but depends on its Motion relative to the observer's space and time.

Using unaccelerated rectangular axes, we have by definition of s.

$$\delta s^2 = \delta t^2 - \delta x^2 - \delta y^2 - \delta z^2$$

So that,

$$\left(\frac{\delta s}{\delta t}\right)^2 = 1 - \left(\frac{\delta x}{\delta t}\right)^2 + \left(\frac{\delta y}{dt}\right)^2 - \left(\frac{\delta z}{\delta t}\right)^2$$

$$= 1 - u^2.$$

Where, u is the ~~smallest~~ resultant velocity.

Hence $M = \frac{M}{\sqrt{(1-u^2)}}$

Thus the Mass Increases as the velocity Increases, the factor being the same as that which determines the FitzGerald Contraction.

- The Increase of Mass with velocity is a property which challenges experimental test. For success it is necessary to be able to experiment with high velocities and to apply a known force large enough to produce appreciable deflection in the fast-moving particle. These conditions are fulfilled by β-particles.

- Confirm the theoretical Increase of Mass, and show that the factor $1/\sqrt{(1-u^2)}$ is at least approximately Correct.

- Unless the velocity is very great the Mass M may be written as

$$M/\sqrt{(1-u^2)} = M + \tfrac{1}{2} M u^2.$$

→ Thus it consists of two parts, the Mass when at rest, together with the second term, which is simply the energy of the Motion. If we can say that the former represents a kind of potential energy concealed in the Matter, Mass can be identified with energy.

→ Similarly the mass of light is simply the E.M. energy of the light.

→ They are measured by different units, and energy E has a Mass E/c^2.

→ But it seems very probable that Mass and Energy are two ways of Measuring what is essentially the same thing, in the same sense that the parallax and distance of a star are two ways of expressing the same property of location.

→ It has to be remarked that, although the Inertial Mass of a particle only comes under physical Measurement in ~~Conversion to~~ Connection with a Change of its Motion, it is just when the Motion is changing that the conception of its Mass is least definite, because it is at that time that the K.E., which forms part of the Mass, is being passed on to another particle or radiated into the surrounding field; and it is scarcely possible to define the Moment at which this energy ceases to be associated with the particle and must be reckoned as broken loose. The amount of energy or Mass in a given region is always a definite quantity, but the amount attributable to a particle is only definite when

$m = \delta \quad \delta = \frac{m}{v}$

the Motion is uniform.

→ The Motion of Matter from one place to another causes an alteration of the gravitational field in the surrounding space. If the Motion is uniform, the field is simply convected; but if the Motion is accelerated, something of the nature of a gravitational wave is propagated outwards. The velocity of propagation is the velocity of light.

→ The exact laws are not very simple because we have seen that the gravitational field modifies the velocity of light; and so the disturbance itself modifies the velocity with which it is propagated.

→ If we wish to speak of the continuous matter present at any particular point of space and time, we must use the term density. Density multiplied by volume in space gives us mass or what appears to be the same thing energy.

→ But from our space-time point of view a far more important thing is density multiplied by a four-D volume of space and time; this is action.

→ Action is thus mass multiplied by time, or energy multiplied by time, and is more fundamental than either.

→ Action is the curvature of the world.

→ In 4-D, there are many coefficients of curvature, but there is one curvature par excellence, which is, of course, an Invariant independent of any Mesh-system. It is the quantity we have denoted by b.

It does not follow that if the natural gravitational field space-time is not flat although there may be no Mass or energy and therefore no action or curvature.

→ There could not be any other world anywhere else because there isn't any "anywhere else".

→ We can see now that if action is something absolute; a configuration giving Minimum action is capable of the absolute definition and accordingly we should expect that the laws of the world would be expressible in some such form.

It is rather curious that there is no action in space → containing only light. Light has Mass 'M' of the ordinary kind, but the invariant Mass (m) vanishes.

→ The coming theory of relativity had cast its shadow before; and physics was already converging to two great generalisations, the principle of least action and the second law of thermodynamics or principle of entropy.

Conclusion

→ 1) The order of events in the external world is a 4-D order.

2) The observer either intuitively or deliberately constructs a system of Meshes (space and time partitions) and locates the events with respect to these.

3. Although it seems to be theoretically possible to describe phenomena without reference to any Mesh system (by a catalogue of coincidences), such a description would be cumbersome. In practice physics describes the relations of the events to our Mesh system; and all the terms of elementary physics and of daily life refer to this relative aspect of the world.

4. Quantities like length, duration, mass, force etc. have no absolute significance; their values will depend on the Mesh system to which they are referred.

5. There is no fundamental mesh-system. In particular problems, and more particularly in restricted regions, it may be possible to choose a mesh-system which follows more or less closely the lines of absolute structure in the world, and so multiply the phenomena which are related to it.

6. The study of the absolute structure of the world is based on the "interval" between two events close together, which is an absolute attribute of the events independent of any Mesh system,

7) This world-geometry has a property unlike that of Euclidean geometry in that the interval between two real events may be real or imaginary.

8) The geodesic, or track of maximum or minimum interval-length between two distant events, has an absolute significance.

9) In Euclidean geometry the geodesics are straight lines. Hence the geometry must be non-Euclidean in a field of gravitation.

(10) Since the tracks of particles in a gravitational field are evidently governed by some law, the possible geometries must be limited to certain types.

(11) The limitation concerns the absolute structure of the world, and must be independent of the choice of mesh-system. Curved no. Practically the only reasonable suggestion is that the world

(12) must be "curved no higher than the first degree," and this is taken as the law of gravitation.

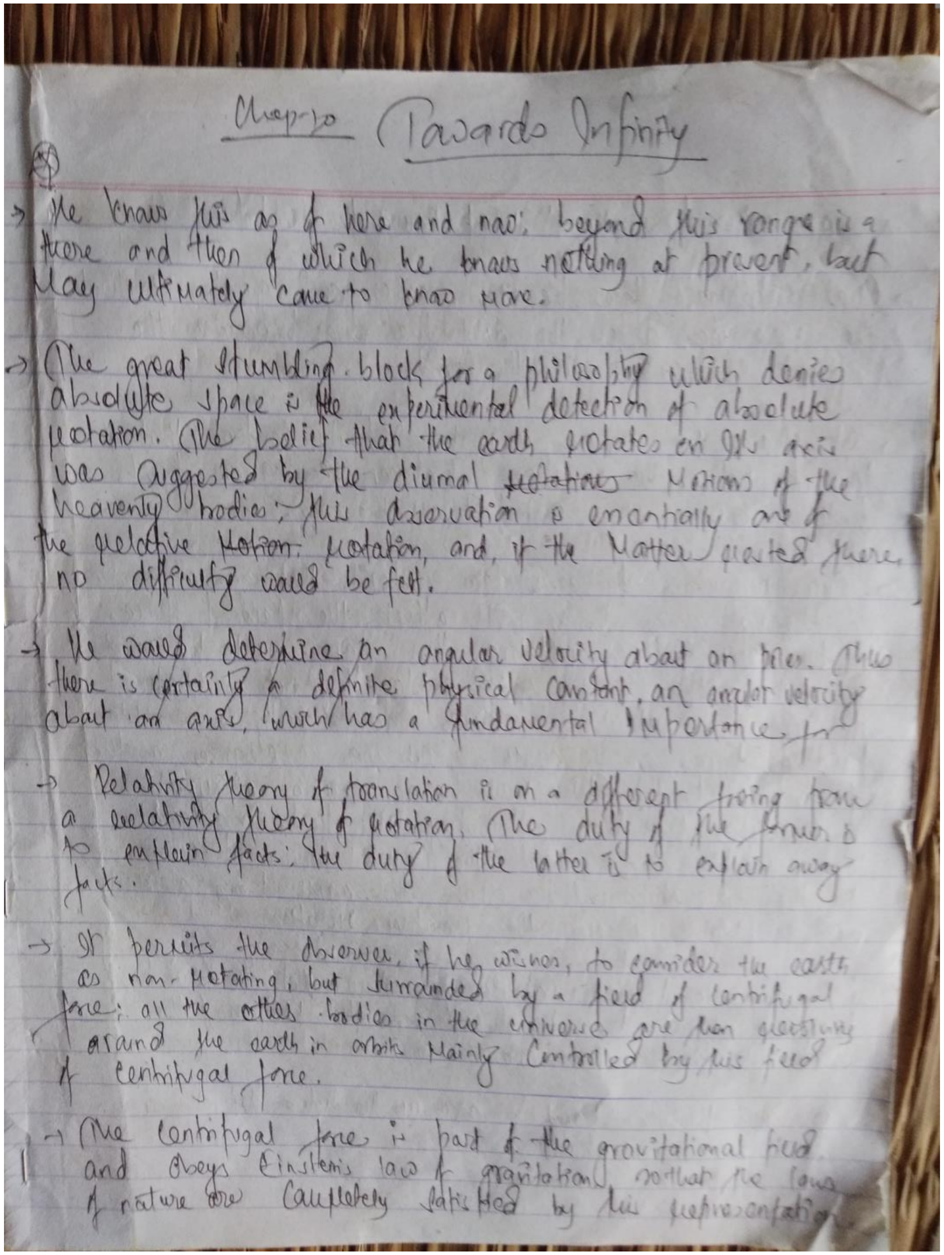
(13) The simplest type of hummock with this limited curvature has been investigated.

(14) The tracks of the geodesics on the hummock are such as to give a very close accordance with the tracks computed by Newton's law of gravitation.

(15) The hummock might more properly be described as a ridge extending linearly. Since the interval-length along it is real or time-like, the ridge can be taken as a time-direction.

15→ The laws of Conservation of energy and Momentum in Mechanics can be deduced from this law of world-curvature.

16→ Certain phenomena such as the FitzGerald Contraction and the variation of Mass with velocity, which were formerly thought to depend on the behaviour of electrical force concerned, are now seen to be general Consequences of the relativity of knowledge.



Chap-10 Towards Infinity

→ We know this as of here and now; beyond this range is a there and then of which we know nothing at present, but may ultimately come to know more.

→ The great stumbling block for a philosophy which denies absolute space is the experimental detection of absolute rotation. The belief that the earth rotates on its axis was suggested by the diurnal ~~rotations~~ motions of the heavenly bodies; this observation is essentially one of the relative ~~motion~~ rotation, and, if the matter rested there, no difficulty would be felt.

→ We would determine an angular velocity about an axis. Thus there is certainly a definite physical constant, an angular velocity about an axis, which has a fundamental importance, for

→ Relativity theory of translation is on a different footing from a relativity theory of rotation. The duty of the former is to explain facts; the duty of the latter is to explain away facts.

→ It permits the observer, if he wishes, to consider the earth as non-rotating, but surrounded by a field of centrifugal force; all the other bodies in the universe are then revolving around the earth in orbits mainly controlled by this field of centrifugal force.

→ The centrifugal force is part of the gravitational field and obeys Einstein's law of gravitation, so that the laws of nature are completely satisfied by this representation

→ an awkward question – "What causes the Centrifugal force."

→ The Centrifugal force becomes greater and greater, so that the more we defer the debt the ~~be~~ heavier the payment demanded in the end.

→ It chases the cause away to Infinity, Content that the laws of nature – the relations between Contiguous parts of the world – are satisfied all the way.

→ Our new law of gravitation admits that a rapid motion of the attracting body will affect the field of force. If the earth is non rotating, the stars must be going round it with terrific speed. May they not in virtue of their high velocities produce gravitationally a sensible field of force on the earth, which we recognise as the Centrifugal field? This would be a genuine elimination of absolute rotation, attributing all effects indifferently to the rotation of the earth the stars being at rest, or to the revolution of the stars the earth being at rest, nothing matter except the relative rotation.

→ In any case, precise Calculations shows that the Centrifugal force could not be produced by the motion of the stars, so far as they are known.

→ We are therefore forced to give up the idea that the signs of the earth's rotation.

→ Due to a rotation relative to any matter we can recognise.

→ Will no doubt reply that the rotation must then be relative to some matter which we have not yet recognised.

→ Physics demands of its scheme of nature something else beside truth, namely a certain quality that we may call convergence. The law of conservation of energy is only strictly true when the whole universe is taken into account; but its value in physics lies in the fact that it is approximately true for a very limited system. Physics is an exact science because the chief conditions of a problem are limited to a few conditions; and it draws near to the truth with ever-increasing approximation as it widens its purview.

→ History, on the other side, is of very often like a divergent series, no approximately approximation to its course is reached until the last term of the infinite series has been included in the data of prediction. Physics, if it wishes to retain its advantage, must take its own course, formulating those laws which are approximately true for the limited data of sense, and extending them into the unknown.

→ The same ~~condition~~ considerations that apply to rotations apply to acceleration, although the difficulty is less striking. We can if we like attribute to the sun some arbitrary acceleration, balancing it by introducing a uniform gravitational field. Owing to this field the rest of the stars will move with the same acceleration and no phenomena will be altered. But then it seems necessary to find a cause for this field. It is not produced by the gravitation of the stars. Our only cause is to pursue the cause further and further towards infinity; the further we put it away, the greater the mass of attracting matter needed to produce it. On the other hand, the earth's absolute acceleration does not intrude on our attention in the way that its absolute rotation does. ←

To determine even roughly the earth's absolute acceleration we should need a fairly full knowledge of the disturbing effects of all the matter in the universe. A similar knowledge would be required to determine the absolute motion rotation accurately; but all the matter likely to exist would have so small an effect, that we can at once assume that the absolute rotation is very nearly the same as the experimentally determined rotation.

→ The theory of relativity, as we have understood it, asserts that our partitions of space and time are introduced by the observer and are irrelevant to the laws of nature and therefore the current quantities of physics, length, duration, mass, force, etc. which are relative to these partitions, are not things having absolute significance in nature. But we have never denied that there are features of the world having an absolute significance.

→ The geodesics or natural tracks have been shown to have an absolute significance, and it is possible in a limited region of the world so to choose space and time partitions such that all geodesics become approximately straight lines. We may call this a "natural" frame for that region, although it is not as a rule the space and time adopted in practice; it is for example the space and time of the observers in the falling projectile, not of Newton's super-observer.

→ Now the rotation of the earth determined by Foucault's pendulum experiment is the rotation referred to this natural frame.

→ Material particles and geodesics are both features of the absolute structure of the World; and a rotation relative to geodesic structure does not seem to be on any different footing from a velocity relative to Matter. There is, however, the striking feature that rotation seems to be relative not merely to the local geodesic structure but to a generally accepted universal frame; whereas it is necessary to specify precisely what Matter a velocity is measured with respect to.

→ The Moon's (local) angular velocity is sometimes given to fourteen significant figures; I doubt if any universal frame is well defined enough for this accuracy. There is no doubt much greater continuity in the ~~de~~ geodesic structure in different parts of the world than in the material structure but the difference is in degree rather than in principle.

→ Permissible known as the law of causality — that only those things are to be regarded as being in causal connection which are capable of being actually observed. This seems to be interpreted as placing Matter on a More above quadratic structure in regard to the formulation of physical laws, though it is not easy to see in what sense a distribution of Matter can be regarded as more favourable than the field of influence in surrounding space which takes its origin from its existence.

The principle that is debatable, that which is favourable to us is determined by the curvature of our own structure and the law of causality seems to impose our own preconceptions on the free interplay of entities in the world outside us.

→ The vague universal frame to which rotation is referred is called the inertial frame. It is definite in the flat space-time far away from all matter.

→ The reason for the term, *

→ We can quite freely use a [illegible] system deviating widely from a inertial frame (i.e. rotating axes). but we have seen that there is postponed debt to pay, even when the inertial frame is used? In that case, there is no gravitational or centrifugal force at infinity; but there is still inertia, which is of the same nature.

→ The distinction between force as requiring a cause and inertia as requiring no cause cannot be sustained.

→ The dels is inevitable whatever Mesh system is used; we are only allowed to choose the fenelit that we take.

→ At Infinity, we have the absolutes geodesic in space-time and we have an arbitrarily drawn Mesh-system. The relation of the geodesics to the Mesh-system decides whether at area shall be termed as rotating or non-rotating; and ideally it is this relation that is determined when a so called absolute rotation is measured.

→ On the other hand uniform translation does not affect the relation of the geodesics to the Mesh-system. If they were straight lines originally, they remain straight lines, thus uniform translation cannot be measured except relative to Matter.

→ There are still definite natural tracks in space-time far beyond the influence of Matter.

→ It is urged that as Matter influences the course of geodesics, it may well be responsible for them altogether; so that a region outside the field of action of Matter could have no geodesics, and consequently no intervals. All the potentials would then necessarily be zero. Various modified forms of this objection arise; but the main feeling seems to be that it is unsatisfactory to have certain conditions prevailing in the world which can be traced away to infinity and so have, as it were, their source at infinity; and there is a desire to find some explanations of the inertial frame as built up through conditions at a finite distance.

→ Now if all intervals vanished space-time would shrink to a point. Then there would be no space, no time, no inertia, no anything. Thus a cause which creates intervals and geodesics must, so to speak, extend the world. We can imagine the world stretched out like a plane sheet; but then the stretching cause - the cause of the intervals - is relegated beyond the bounds of space and time, i.e. to infinity.

→ An alternative way is to inflate the world from ~~outside~~ inside, as a balloon is blown out. In this case the stretching ~~xx~~ force isn't relegated to infinity, and outside the scope of experiment, it is acting at every point of space and time, turning the world to a sphere.

We thus get the idea that space-time may have an essential curvature on a great scale independent of the small hummocks due to recognised matter.

→ It may be asked, what have we gained by substituting a natural curvature of space-time for a natural stretched condition corresponding to the inertial frame? As an explanation, nothing. But there is this difference, that the theory of the inertial frame can now be included in the differential laws of gravitation instead of remaining outside and additional to the law.

-> Spherical surface is not easy to imagine. We have to think of the properties of the surface of a sphere - the 2-D case, and try to conceive something similar applied to 3-D space. Stationing ourselves at a point let us draw a series of spheres of successively greater radii.

The surface of a sphere of radius 'r' should be proportional to r^2; but in spherical space the areas of the more distant spheres begin to fall below the proper proportion.

-> Ultimately we reach a sphere of biggest possible area, and beyond it the areas begin to decrease.

-> There is nothing beyond and yet there is no boundary. On the earth's surface there is nothing beyond our own antipodes but there is no boundary there.

-> The difficulty is that we try to realise this spherical world by imagining how it would appear to us and to our measurements. There has been nothing in our experience to compare it with, and it seems fantastic.

-> But if we could get rid of the personal point of view, and regard the sphericity of the world as a statement of the type of order of events outside us, we should think that it was a simple and natural order which is as likely as any other to occur in the world.

→ The centrifugal force increases until we reach the sphere of greatest area, and then, still obeying the law of gravitation, diminishes to zero at the antipodes. The debt has paid itself automatically.

→ A new constant has been introduced into the law of gravitation which gives the world a definite expansion.

→ Granted extension, so that the intervals are not invariably zero, we can determine geodesics everywhere, and hence mark out the inertial frame.

→ Spherical space-time, that is to say a 4-D continuum of space and imaginary time forming the surface in 5-D, has been investigated by Prof. de Sitter.

→ If real time is used the world is spherical in it's space-dimension, but open towards plus and minus infinity in it's ~~time dimension~~ time dimension, like an hyperboloid. This happily relieves us of the necessity of supposing that as we progress in time we shall ultimately come back to the instant we started from!

→ Einstein has a theory of the world in which the (history) action can actually happen; but in de-Sitter's theory, it is rather an abstraction, because, as he says, "all the paradoxical phenomena can only happen after the end or before the beginning of eternity,

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→ Owing to curvature in the time dimension, as we examine the condition of things further and further from our starting point, as time begin to run faster and faster, or to put it another way natural phenomena and natural clocks slow down.

→ When we reach half-way to the antipodal point, time stands still. There is no possibility of getting any further, because everything including light has come to rest here. All that lies beyond is for ever cut off from us by this barrier of time, and light can never complete its voyage around the world.

→ We thought time was standing still, but it was really proceeding there at the usual rate, as if in a fifth dimension of which we had no cognizance. Casting an eye back on our old home we should see that time apparently had stopped still there.
Time in the two places is proceeding in directions at right angles, so that the progress of time at one point has no relations to the perception of time at the other point.
The reader will easily see that a being confined to the surface of a sphere and not cognizant of a third dimension, will, so to speak, lose one of his dimensions altogether when he watches things occurring at a point go away.
He regains it if he visits the spot and so adapts himself to the two dimensions which prevail there.

→ The most remote objects known are the spiral nebulae.

→ If natural phenomena are slowed down there, the vibrations of an atom are slower, and the characteristics spectral lines will appear displaced to the red.

→ The motions in the line of sight of a number of nebulae have been determined, chiefly by Prof. Slipher.

→ But there is no doubt that large receding motions greatly preponderate. This may be a genuine phenomenon in the evolution of the material universe; but it is also possible that the interpretation of spectral displacement as a receding velocity is erroneous; and the effect is really the slowing of atomic vibrations predicted by de Sitter's theory.

→ Einstein's world is cylindrical, curved in the three space dimensions, and straight in the time dimension. Since time is no longer curved the slowing of phenomena at great distances from the observer disappears, and with it the slight experimental support given to the theory by the observations of spiral nebulae. There is no longer a barrier of eternal rest, and a ray of light is able to go round the world.

→ de Sitter's and Einstein's hypotheses have been made; and in both cases the radius is thought to be of the order 10^{25} times the distance of the earth from the sun.
A ray of light from the sun would thus take about 1000 million years to go round the world, and after the journey the rays would converge again at the starting point, and then diverge for the next circuit.

→ The convergent would have all the characteristics of a real sun, so far as light and heat are concerned, only there would be no substantial body present.

→ Then corresponding to the sun we might see a series of ghosts occupying the position where the sun was 1000, 2000, 3000 etc. million years ago, if (as seems possible probable) the sun has been luminous so long.

→ Perhaps one or more of the many spiral nebulae are really phantoms of our own stellar system.

→ It is, however, unlikely that the light rays after their long journey would converge with the accuracy which this theory would require. The minute deflections by the various gravitational fields encountered on the way would turn them aside and the focus would be blurred. Moreover, there is a likelihood that the light would gradually be absorbed or scattered by matter diffused in space, which is encountered on the long journey.

→ It is sometimes suggested that the return of the light-wave to its starting point can not easily be regarded as due to the force of gravitation, there being ~~effect~~ sufficient mass distributed through the universe to control its path in a closed orbit.

→ It is quite possible for light to return to it's starting point can not easily be regarded as due to the force of gravitation, there being sufficient mass distributed through the universe to control its path in a closed orbit.

→ It is quite possible for light to return to its starting point in a world without gravitation. We can have flat space-time into a cylinder and join the edges; the geometry will still be Euclidean and there will be no gravitation; but a ray of light can go right around the cylinder and return to the starting ~~point~~ point in space. Similarly in Einstein's more complex type of cylinder (three dimensions curved and one dimension linear) it seems likely that the return of the light is due, as much as to the Connectivity of his space, as to the non-Euclidean properties which express the gravitational field.

→ For Einstein's cylindrical world it is necessary to postulate the existence of vast quantities of Matter (not needed in de Sitter's theory) far in excess of what has been revealed by our telescopes.

This additional Matter may either be in the form of distant stars and galaxies beyond our limits of vision, or it may be uniformly spread through space and make notice by its low density. There is a definite relation between the average density of Matter and the radius of the world; the greater the radius the smaller must be the average density.

→ Two objections to this theory may be urged. In the first place, absolute space and time are restored for phenomena on a cosmical scale.

→ The world taken as a whole has one direction in which it is not curved; that direction gives a kind of absolute time distinct from space. Relativity is reduced to a local phenomenon, and although this is quite sufficient for the theory hitherto described, we are inclined to look on the limitation rather grudgingly.

→ If the conception of absolute time turns up in a new form in a theory of phenomena on a cosmical scale, as to which no experimental knowledge is yet available. Just as each limited observer has his own particular separation of space and time, so a being coextensive with the world might well have a special separation of space and time natural to him. It is the time for this being that is here dignified by the title "absolute."

→ The revised law of gravitation involves a new constant which depends on the total amount of matter in the world; or conversely the total amount of matter in the world is determined by the law of gravitation.

→ We can see that, the constant in the law of gravitation being fixed, there may be some upper limit to the amount of matter possible; as more and more matter is added in the distant parts, space curves round and ultimately closes; the process of adding more matter must stop, because there is no more space, and we can only return to the region to the region already dealt with. Then there seems nothing to prevent a defect of matter, leaving space ~~enclosed~~ unclosed. Some mechanism seems to be needed, whereby either gravitation creates matter, or all the matter in the universe conspires to define a law of gravitation.

→ For it leads to the result that the extension of space and time depends on the amount of matter in the world — partly by its direct effect on the curvature and partly by its influence on the constant of the law of gravitation. The more matter there is the more space is created to contain it, and if there were no matter the world would shrink to a point.

→ Profound saying. Noch Philosophy." If there were no matter in the universe, the law of gravitation would fall to the ground."

→ In a space without absolute features, an absolute rotation would be as meaningless as an absolute translation; accordingly, the existence of an experimentally determined quantity generally identified with absolute rotation requires explanation.

→ It was remarked on Pg. 36 that it would be difficult to devise a plan of the world accordingly, the existence of an ~~experimentally determined quantity~~ to which uniform motion has no significance but non-uniform motion is significant; but such a world has been arrived at — a plenum, of which the absolute features are intervals and geodesics. In a limited region this plenum gives a natural frame with respect to which an acceleration or rotation (but not a velocity) capable of absolute definition can be measured. In case of rotation the local distortions of the frame are of comparatively little account; and this explains why in practice rotation appears to have reference to some world-wide

Inertial frame. Thus absolute rotation does not indicate any logical flaw in the theory hitherto developed; and there is no need to accept any modification of our views.

→ Einstein's cylindrical space-time was suggested, once this cannot exist without matter to keep it stretched. Now we freely admit that our assumption of perfect flatness in the remote parts of space was arbitrary, and there is no justification for insisting on it. A small curvature is possible both conceptually and experimentally.

→ We are scarcely sufficiently advanced to offer a final opinion; but the conception of cylindrical space-time seems to be favoured by this new development of the theory.

→ May be urged that our geodesics ought not to be regarded as fundamental; a geodesic has no meaning in itself; what we are really concerned with is the relation of a particle following a geodesic to all the other matter of the world and the geodesic cannot be thought of apart from such other matter. We would reply: "Your particle of matter is not fundamental; it has no meaning in itself; what you are really concerned with is the field - the relation of the geodesics about it to the other geodesics in the world. And matter cannot be thought of apart from the field.

Chap-11 Electricity & Gravitation

→ The theory of relativity deduces from ~~the~~ geometrical principles the existence of gravitation and the laws of Mechanics of Matter. Mechanics is derived from geometry, not by adding arbitrary hypotheses, but by removing unnecessary assumptions.

→ We cannot rest satisfied until a deeper unity between the gravitational and electrical properties of the world is apparent. The electron, which seems to be the smallest particle of Matter, is a singularity in the gravitational field and also a singularity in the electrical field.

→ The gravitational field is the expression of some state of the world, which also manifests itself in the natural geometry determined with measuring appliances; the electric field must also express some states of the world but we have not as yet connected it with natural geometry.

→ We have based everything on the "Interval" which, it has been said, is something which all observers, whatever their motions or whatever their mesh-system, can measure absolutely, agreeing on the result.

→ But if A is in motion relative to B and wishes to hand his standards to B to check the measures, he must stop their motion; this means in practice that he must bombard his standards with material molecules until they come to rest. Is it fair to assume that no alteration of the standard is caused by this process? Or if A measures time by the vibrations of a hydrogen atom, and space by the wave-length of the vibrations, still it is necessary to stop the atom by a collision in which electrical forces are involved?

→ To compare intervals in different directions at a point in space and time does not require this comparison with a distant standard. The physicist's method of describing phenomena near a point P is to lay down for comparison
1) Mesh-system 2) a unit of length,
which can also be used for measuring time, the velocity of light being unity.

→ If there is this ambiguity the only possible course is to lay down 1) a mesh-system filling all space and time considered,
2) a definite unit of interval, or gauge, at every point of space and time. The geometry of the world referred to such a system will be more complicated than that of Riemann hitherto used; and we shall see that it is necessary to specify not only the 10 g's but four other functions of position, which will be found to have an important physical meaning.

→ The observer will naturally simplify things by making the units of gauge at different points as nearly as possible equal, judged by ordinary comparisons. But the fact remains that, when the comparison depends on the route taken, exact equality is not definable; and we have therefore to admit that the exact standards are laid down at every point independently.

→ But, except in the particular case of flat space, there is no means of defining exactly what coordinates at Q are the same as those at P.

→ But to exact work the only course is to lay down a definite mesh-system extending throughout space, the precise mode of the partitions being necessarily arbitrary, we now find that we have to add to this by placing in each mesh a gauge whose precise length must be arbitrary. Having done this the next step is to make measurements of intervals using our gauges. This connects the absolute properties of the world with our arbitrarily drawn mesh-system and gauge-system. And so by measurement we ~~define~~ determine the g's and the new additional quantities, which determine the geometry of our chosen system of reference and at the same time contain within themselves the absolute geometry of the world - the kinds of space-time which exists in the field of our experiment.

→ Having laid down a unit-gauge at every point, we can speak quite definitely of the change in interval-lengths of a measuring rod moved from point to point, meaning of course the change compared with the unit-gauges. Let us take the rod of interval-length l at P, and move it successively through the displacements $dx_1, dx_2, dx_3, \ldots$ and let the result be to increase its length in terms of the gauges by the amount δl. The

The change depends as much on the difference of the gauges at the two points as on the behaviour of the rod; but there is no possibility of separating the two factors.
It is clear that δ will not depend on l, because the change of length must be proportional to the original length.

→ Further it will not depend on the direction of the rod either in its initial or final position because the interval-length is independent of direction. (of course, the space-length would change, but that is already taken care of by the g's).
δ can thus only depend on the displacements dx_1, dx_2, dx_3, dx_4, and we may write it

$$\delta = K_1 dx_1 + K_2 dx_2 + K_3 dx_3 + K_4 dx_4$$

So long as the displacements are small. The coefficients K_1, K_2, K_3, K_4 apply to the neighborhood of P and will in general be different in different parts of space.

→ Yet in the limit there is a definite small interval between P and Q when they are sufficiently close together.

→ Meaning of these new coefficients K let us briefly recapitulate what we understand by the g's.
Primarily they are quantities derived from experimental measurements of intervals and describe the geometry of the space and time partitions which the observer has chosen.
As consequential properties, they describe the field of force with which he perceives himself surrounded.

They relate to the particular mesh-system of the observer, and by altering his mesh-system, he can alter their values, though not entirely at will. From their values can be deduced intrinsic properties of the world, the kind of space-time in which the phenomena occurs.
Further they satisfy a definite condition - the law of gravitation, so that not all mathematically possible space-times and not all arbitrary values of the g's are such as can occur in nature.

→ All this applies equally to the K's, if we substitute gauge system for mesh-system, and some at present unknown force for gravitation.

→ Further we may ~~except~~ expect that they will have to satisfy some law corresponding to the law of gravitation, so that not all arbitrary values of the K's are such as ~~one~~ can occur in nature.

→ K's must refer to E.M. field.

→ E.M. field is, in fact, specified at every point by the values of four quantities viz.: the three components of E.M. vector potential, and the scalar potential of electrostatics.

→ Taking the ordinary unaccelerated rectangular coordinates x, y, z, t let us write $F, G, H, -\Phi$ for K_1, K_2, K_3, K_4 then pg → 157

$$\frac{dl}{l} = \epsilon = F\,dx + G\,dy + H\,dz - \Phi\,dt$$

Then by Integration

$$\log l + \text{Const.} = \int (F\,dx + G\,dy + H\,dz - \Phi\,dt)$$

If F, G, H, Φ are the potentials of E.M. Theory, these are precisely the expressions for the three components of Magnetic force and the three components of electric force, given in the text-books.

→ That the electric and Magnetic forces are zero in the Intervening space and time.

→ Even when the co-ordinate system has been defined, the E.M. potentials are not unique in value, but arbitrary additions can be made provided these additions form a perfect differential.

→ The E.M. forces on the other hand are Independent of the gauge system, which is eliminated by curling.

→ Four new quantities appearing in our extended geometry may actually be the four potentials of E.M. theory; and further, when there is no E.M. field our previous geometry is valid.

→ We do, however, generalise it so that it applies when a gravitational field is present at the same time - not merely as given by Maxwell for flat space-time.

One deflection of E.M. waves (light) by a gravitational field is duly contained in these generalised laws.

→ The laws of gravitation and of the E.M. field are not the laws but one law, as the geometry of g_{ik} and the k_i the is one geometry.

→ In the new geometry there is a fifth arbitrariness, namely that of the selected gauge-system. It is found that the law identity expresses the law of conservation of electric charge.

→ We describe this by saying that in curved space, direction is not integrable and it is the non-integrability of direction which characterises the gravitational field. In the case considered the length would be preserved throughout the circuit; but it is possible to conceive a more general kind of space in which the length which is was interrupted to preserve throughout the circuit, as well as the directions, disagreed in question to the starting point with that originally drawn. In that case length is not integrable, and the non-integrability of length characterises the E.M.

→ A 2-D observer cannot ascertain by any observation whether he is on a plane or a cylinder, a sphere or any other convex surface of the same total curvature.

The geometrical potentials (K) obey the recognized laws of E.M. potentials, and each entity in the physical theory has its exact analogue in the geometrical theory; but is this formal correspondence a sufficient ground for identification?

→ This is not the thing I'm speaking of, though it behaves exactly like it in all respects.

→ The main features of the absolute world are so simple, that there is a redundancy of apparatus at our disposal; and probably all that there is to be known could theoretically be found out by exploration with an uncharged particle.

→ The gravitational field is more sensitively explored with a moving particle than a scale.

→ Einstein's curved space appears in a perfectly natural manner in this theory; no part of space-time is flat, even in the absence of ordinary matter, for that would mean infinite radius of curvature, and there would be no natural gauge to determine, for example, the dimensions of an electron - the electron could not know how large it ought to be, unless it had something to measure itself against.

→ The curvature of space indirectly provides the gauge which we use for measuring the amount of matter in the world.

→ Since the curvature is not independent of the gauge, [illegible]

→ The law of nature is that the actual state of the world is that which is statistically most probable.

→ The theory also shows that the mass of a portion of matter is necessarily positive; on the original theory no adequate reason is given why negative matter should not exist.

→ Finally the theory suggests a mode of attacking the problem of how the electric charges of an electron is held together; at least it gives an explanation of why the gravitational force is so extremely weak compared with the electrical force.

It will be remembered that associated with the mass of the sun is a certain length, called the gravitational mass, which is equal to 1.5 km. In the same way the gravitational mass or radius of an electron is $7 \cdot 10^{-56}$ cm. Its electrical properties are similarly associated with a length 2×10^{-13} cm, which is called the electrical radius.

→ The theory suggests that the ratio of the gravitational to the electrical radius, $3 \cdot \times 10^{42}$ ought to be of the same order as the ratio of the latter to the radius of curvature of the world.

→ This would require the radius of space to be of the order 6×10^{25} cm or 2×10^{7} parsecs, which though somewhat larger than the provisional estimates made by de Sitter, is within the realm of possibility.

Chap-12 On the Nature of Things:-

→ The constructive elements of the theory of relativity are based on two principles which have been enunciated – the restricted principle of relativity, and the principle of equivalence.
i.e → The uniform motion and fields of force are purely relative.

→ Which can be admitted or denied; if admitted, all the observational results obtained by us can be deduced mathematically without any reference to the ideas of space, time, or force, described in this book.

→ The question arises, are these merely illustrations of the mathematical argument, or illustrations of the actual processes of nature.

→ The physicist, so long as he thinks as a physicist, has a definite belief in a real world outside him.

→ When therefore we are asked whether the four-dimensional world may not be regarded merely as an illustration of mathematical processes.

→ The real three-dimensional world is obsolete, and must be replaced by the 4-D space-time with non-Euclidean properties.

→ But the 4-D world is no mere illustration; it is the real world of physics, arrived at in the recognised way by which physics has always (rightly or wrongly) sought for reality.

→ All the appearances are accounted for if the real objects is 4-D and the observers are merely measuring the different 3-D appearances or sections; and it seems impossible to doubt that this is the true explanation.

→ Reality is only obtained when all conceivable points of view have been combined.

→ The immediate perception of the world with one eye is a 2-D appearance. But we have two eyes, and these combine the appearances of the world as seen from two positions; in some mysterious way the brain makes the synthesis by suggesting solid relief, and we obtain the familiar appearance of 3-D world.

→ The next step was to combine the appearances for all possible states of uniform motion of the observer. The result was to add another dimension to the world, making it 4-D. Next the synthesis was extended to include all possible variable motions of the observer. The process of adding dimensions stopped, but the world became non-Euclidean; a new geometry called Riemannian geometry was adopted.
→ Finally the points of view of observers varying in size in any way were added; and the result was to replace the Riemannian geometry by a still more

general geometry described in the last chapter.

→ It seems a natural procedure to explain the complex in terms of the simple, but it carries with it the necessity of explaining the familiar in terms of the unfamiliar.

→ In the relativity theory of nature the most elementary concept is the point-event.

→ The aggregate of all the point-events is called the world.

→ Thus the statement that the world is 4-D contains an implicit reference to some ordering relation. This relation appears to be the Interval.

→ But in physics we are concerned not with the nature of the relation but with the number assigned to express its intensity; and this suggests a graphical representation, leading to a geometrical theory of the world of physics.

→ The formula given is just an average summary which suffices for our coarse methods of investigation, and holds true only statistically. Just as statistical averages of one community may differ from those of another, so may this statistical formula for one region of the world differ from that of another. This is the starting point of the infinite variety of nature.

- The ten g's are concerned not only with Intrinsic properties of the world, but with our arbitrary system of Identification-numbers for the point-events; or, as we have previously expressed it, they describe not only the kind of space-time, but the nature of the arbitrary mesh-system that is used.

→ Mathematics shows the way of steering through the difficulty by fixing attention on expressions called tensors, of which $B^{\rho}_{\mu\nu\sigma}$ and $G_{\mu\nu}$ are examples.

→ A tensor does not express explicitly the measure of an Intrinsic quality of the world, for some kind of mesh-system is essential to the idea of measurement of a property, except in certain very special cases where the property is expressed by a single number termed an Invariant.

→ In empty space, $G_{\mu\nu} = 0$

In space containing matter $G_{\mu\nu} = K_{\mu\nu}$

where $K_{\mu\nu}$ contains only physical quantities which are perfectly familiar to us, viz, the density and state of motion of the matter in the region.

→ First expresses some law ~~thing~~ existing in the world, so that the point-events by natural necessity tend to arrange their relations in conformity with this equation. But when matter intrudes it causes a disturbance ~~of~~ or strain of the natural linkages; and a rearrangement takes place to the extent indicated by the second equation.

→ We have decided that in empty space $G_{\mu\nu}$ vanishes. Here is our opportunity.

In default of any other suggestions as to what the vanishing of $G_{\mu\nu}$ might mean, let us say that the vanishing of $G_{\mu\nu}$ ~~might~~ mean, ~~let~~ mean emptiness; so that $G_{\mu\nu}$, if it does not vanish, is a condition of the world which distinguishes space said to be occupied from space said to be empty.

Hitherto $G_{\mu\nu}$ was merely a formal outline to be filled with some undefined ~~Constants~~ contents; we are ~~as~~ as far as ever from being able to explain what these contents are; but we have now given a recognizable meaning to the completed picture, so that we shall know it, when we come across it in the familiar world of experience.

→ The two equations are accordingly merely definitions — definitions of the way in which certain states of the world (described in terms of the Indefinables) impress themselves on our perceptions. When we perceive that a certain region of the world is empty, that is ~~nec.~~ merely the mode in which our senses recognise that it is curved no higher than the first degree. When we perceive that a region contains Matter we are recognising the intrinsic curvature of the world; and when we believe we are measuring the Mass and Momentum of the Matter (relative to some area of reference) we are measuring certain components of world-curvature (referred to time axes).

→ We need not regard Matter as a foreign entity causing a disturbance in the gravitational field; the disturbance is Matter.

– By the time the eqn $G_{\mu\nu} = K_{\mu\nu}$ is encountered, both sides of the eqn are well defined quantities. Their necessary Identity is overlooked, and the eqn is regarded as a new law of nature.
This is the fault of Introducing the scale and clock prematurely. For our part we prefer first to define what Matter is in terms of the elementary Concepts of the theory; then we can Introduce any kind of scientific apparatus, and finally determine what property of the world that apparatus will Measure.

→ Matter defined in this way obeys all the laws of Mechanics Including Conservation of energy and Momentum.

→ The reality corresponding to our perception of the Motion of Matter is an element of the Complex thing we call feeling. What we might perceive as a plexus of nerve-disturbances is really in itself a feeling, and the succession of feelings which Constitutes a Man's Consciousness is the Reality which produces in our Minds the perception of the Motions of his brain. These elements of feelings have relations of nextness or Contiguity in space.

which are exemplified by the slight-perceptions of Contiguous points; and relations of succession in time which are exemplified by all perceptions.

→ Out of these two relations the future theorist has to build up the world as best he may. Two things may perhaps help him. There are many lines of mathematical thoughts which indicate that distance or quantity may come to be expressed in terms of position in the wide sense of analysis situs. And the theory of space-curvature hints at a possibility of describing matter and motion in terms of extension only.

→ The eqn $G_{\mu\nu} = K_{\mu\nu}$ is a kind of dictionary explaining what the different components of world-curvature mean in terms ordinarily used in mechanics.

→ ρ is the ... density of the matter, u, v, w its component velocities, and P_{11}, P_{12} ... P_{33} the components of the internal stresses which are believed to be analysable into molecular movements.

→ Is it legitimate to make identification on such a wholesale scale? Having identified T_{44} as density, can we go on to identify another quantity T_{34} as density multiplied by velocity? It is as though we identified one "thing" as air, and a quite different "thing" as wind.

→ All identifications are at this stage provisional being subject to subsequent test by observation.

→ Velocity is the ratio of Certain Components of $T_{\mu\nu}$, and only exists when $T_{\mu\nu}$ is not zero. (The Matter (i.e. energy) is the only thing that can have a velocity relative to the frame of reference. The velocity of the world-structure or aether, where the $T_{\mu\nu}$ vanish, is always of the Indeterminate form $0 \div 0$. On the other hand acceleration and rotation are defined by means of the $g_{\mu\nu}$ and exist be whatever there exists so that the acceleration and rotation of the world-structure or aether relative to the frame of reference are determinate.

→ Notice that acceleration is not defined as the change of velocity; it is an Independent entity, much simpler and more universal than velocity. It is from a Comparison of these two entities that we ultimately obtain a definition of time.

→ In the present theory, this field of acceleration is described by the $g_{\mu\nu}$. There is no such thing as a "field of velocity" in empty space; but there is in a material ocean,

→ Acceleration is a comparatively simple quality present wherever there is geodesic structure, i.e. to say everywhere. Velocity is a highly complex quality existing only where the structure is itself more than ordinarily complicated, viz. in Matter.

→ The 4 relations states that, provided the Mesh-system is drawn in one of a certain number of ways, mass (or energy) and Momentum will be Conserved.

→ When the kind of space-time is such that a strict partition of this kind A is impossible, strict conservation does not exist; but we retain the principle as formally satisfied by attributing energy and Momentum to the gravitational field.

→ The laws of electrodynamics appear in like Manner to depend Merely on the Identification of another permanent thing - electric Charge. [→ with Weyl's Theory]

→ Action is generally regarded as the Most fundamental thing in the real world of physics, although the mind passes it over because of its lack of permanence;

→ Where Science has progressed the farthest, the mind has but regained from Nature that which the mind has put into ~~future~~ nature.

→ There must be other forces or Conditions which govern the form and size of an electron; under E.M forces alone it would expand Indefinitely