

Tests of Relativity Theory.¹

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"They say miracles are past; and we have our philosophical persons, to make modern and familiar, things supernatural and causeless. Hence it is that we make trifles of terrors, ensconcing ourselves into seeming knowledge, when we should submit ourselves to an unknown fear."—SHAKESPEARE ("All's Well that Ends Well").

THOSE who were fortunate enough to attend the meeting of the American Physical Society at Kansas City in January, found ample food for reflection on the strange but interesting position into which the experimental tests of the consequences of the theory of relativity have now passed.

This theory, first received with reluctance, is now held with extreme tenacity. In some form or other, it has come to stay. It can be modified, but not annihilated. It may, indeed, fall into line with evolution which every one believes, few can define, and no one can "explain." Its disproof has become a far more formidable task than its proof.

Those, however, who carry relativistic ideas beyond their proper sphere of mathematical physics will do well to ponder the intensive limerick of Father Ronald Knox—

"There was a young man who said God
Must think it excessively odd
That the sycamore tree
Just ceases to be
When there's no one about in the Quad."

But surely we are wandering from Kansas!

What then are the experimental tests to which the theory or theories of relativity may be subjected? Mainly five:

(1) The gradual shift of the perihelion of Mercury stated to be 41" per century and found by Einstein to be 43". Here, as elsewhere, no sooner is the calculated found to agree with the observed value, than the latter becomes elusive and fresh calculation gives widely differing numbers, 38" or even 29", so that Einstein has to build not on a rock but on a quicksand.

(2) The bending of the rays of light passing near the sun's surface, verifiable only at time of total eclipse. This story is too well known to be retold. British and also, especially, American astronomers are well satisfied that the verification is amply complete; but there are many astronomers and physicists who are well aware that this verified effect may be assigned to a number of other causes, particularly to refraction.

(3) At Kansas City, Dr. St. John gave a most complete account of his exhaustive inquiry into the shift towards the red in the spectrum of the sun, a shift to which Einstein attached so much importance that he is reported to have said that if the shift did not exist, then his theory of relativity was wrong. This statement is not upheld by Silberstein, who in his exquisite

treatise on "The Theory of Relativity" (p. 392) points out that the period of an atom on the sun need not necessarily be the same as the corresponding period of a similar atom on the earth, as is commonly assumed. The full relation is

$$\lambda_{\text{sun}}/\lambda_{\text{earth}} = \left(1 + \frac{M}{c^2 R}\right) \tau_{\text{sun}}/\tau_{\text{earth}},$$

where λ is the wave-length corresponding to period τ ($\lambda = c\tau$, of course), M is the mass, R the radius of the sun, and c as usual the velocity of light. Einstein assumes $\tau_{\text{sun}} = \tau_{\text{earth}}$ (but it need not be so),² and in that case $\lambda_{\text{sun}}/\lambda_{\text{earth}} = 1 + \frac{1.75}{8 \times 10^5}$, so that $d\lambda/\lambda = 2.11 \times 10^{-6}$, amounting to 0.008 of an Ångström unit in the blue.

This shift is certified by St. John and by Evershed to be true for the sun. Incidentally the testing of this relation has stimulated an enormous amount of research into the character and motion of the sun's atmosphere. In addition to the horizontal motions due to the sun's rotation and other causes, there are vertical motions varying with elevation, each producing its baffling Doppler effect overlapping the Einstein shift. Strangely enough, the pressure shift can be ignored, for it is estimated, even at the very base near the photosphere, that the pressure of this flaming atmosphere fourteen thousand kilometres thick is but one-tenth of our atmosphere!

Where calcium is first ionised the pressure is but one ten-thousandth, and passing upwards through the regions of the sodium D lines on to the H_α and H_β , we arrive near the top to a pressure of 10^{-13} earth's atmosphere where Ca^+ exists, and the calcium atom enjoys the privilege of losing a second electron.

The full evidence, standing by itself, would testify as much to the skill of the astronomers as to the accuracy of the theory, without any reflection on their transcendent honesty of purpose.

But the real treat of the meeting was yet to come. St. John threw on the screen a photograph of the spectra of Sirius and of its illustrious companion, the White Dwarf. The consequent applause of a large audience told its own tale. The spectrum of the companion was bordered on each side by the scattered light of Sirius. On the right at the red end the companion's spectrum was conspicuously clear; at the other end the blue of Sirius largely overwhelmed it. The predicted shift in this case is 34 times that in the sun, amounting to 21 km./sec., while the measured shift gave for H_β , 26 km./sec.; for H_γ , 21 km./sec.; for other lines, 22 km./sec.—mean, 23 km./sec. Here was indeed an unmistakable and emphatic triumph for Einstein of undoubted and overwhelming importance. Shall we not also pay a tribute to the genius of Eddington, who foresaw the possibility of a gaseous star of atoms completely stripped, and therefore giving rise to little

¹ From a lecture given to the Physical Society of McGill University, Montreal, January 1926.

² This is the answer to Sir Oliver Lodge's recent letter to NATURE (December 26, 1925, p. 938).

radiation pressure, resulting in a compactness hitherto unconceived, amounting to a density fifty thousand times that of water?

(4) At a joint meeting with the American Association for the Advancement of Science (a close relative of the British Association in type and design), the American Physical Society had the pleasure at Kansas of hearing their illustrious president, D. C. Miller, give a clear and interesting account of his latest results on the famous Michelson-Morley-Miller experiment as carried out by him on Mount Wilson. He has, in 1925, carried out a long series of continuous experiments which exceed in quantity and weight all previous experiments of this type. He has taken every precaution of which the most careful of physicists is capable; he has listened and given heed to the suggestions of critical friends, for he is a man without enemies. He has kept aloof from preconceptions and refused to be dragged into controversy. *He proclaims definitely a positive result indicating an earth motion through space of 10 km./sec.* The direction of motion is 6° from the south pole of the solar system, as if our system was like a falling leaf moving broadside on to its proper motion. It will be recollected that in 1887 Michelson and Morley obtained a displacement of 0.02 of an interference fringe, whereas the stagnant ether theory indicated that $2v^2L/c^2\lambda$ should give 0.4 of the said fringe. This was *assumed* to be a null effect.

In 1905 Morley and Miller at Cleveland obtained 0.0075 out of 1.5. Then followed the Rayleigh and Bruce double refraction experiment, the Trouton and Noble capacity experiment, the Fitzgerald and Lorentz shortening theory, and ultimately the special and generalised theories of relativity of Einstein.

Now, mixing metaphors, we see the very experiment, which first started the ball a-rolling, turning round to bite the hand which fed it. Yet we seek intuitively, and therefore possibly wrongfully, for some explanation of Miller's result other than the abandonment of the theory of relativity. Why? Because other experiments are in favour of it? Partly, no doubt. Chiefly, I think, because the space contraction and time elongation of Einstein make the Maxwell equations transformable, and because the change of mass with speed, well verified for β -rays, agree with a rational outlook on a universe where we find only electrical phenomena exhibited as energy in a metrical space-time. Minkowski's work is as persuasive as a great experiment. But the matter will not rest here, for already American physicists are contemplating more experiments at different levels and localities. Rumour has it that Millikan has in hand a portable apparatus. Critics have pointed out that 10 km./sec. a second on Mount Wilson and zero at sea-level would perturb the agreement of astronomical data from various observatories. But Miller has never suggested zero at sea-level, and observatories do have 'personal equations' no less than individual observers. The situation is one requiring patience and experiment rather than speculation at present.

Miller has, however, taken a further step which is quite independent of the positive result of 10 km./sec. above stated, and no less of his deduced direction of motion. He finds that he can get a satisfactory ex-

planation of all his results if he assumes that the solar system is moving with a velocity of 200 kilometres a second (*or more, not less*), relative to the ether. If that is so, then the earth must *drag* 95 per cent. of the ether with it and 5 per cent. must *slip* past the earth. Here we have a revival of the ideas of Stokes, with possibly Planck's addition of immense compressibility due possibly to gravitation. To the writer this idea suggests profound difficulty. For example, the ether would have a vastly larger condensation round the sun than round the earth. However that may be, it appears true that if Miller's results are confirmed at different places, then all our theories go into the melting-pot, relativity and all, and a patient resurvey must commence to unravel afresh order from chaos. The only grave mistake which we can make at present is to treat Miller's main results otherwise than seriously.

(5) It is a relief to pass from the profound difficulties of the second-order experiments to the conspicuous success of the great first-order effect devised by Michelson, advocated strenuously by Silberstein, and carried out so efficiently by Gale and his co-workers. The results of the famous Chicago rotation experiment are equally explainable by the old view of a stagnant ether, or by the Einstein relativity theory. It is no less opposed to the Stokes drag theory, or to Miller's suggestion of 10 km./sec. slip and 190, or more, km./sec. drag. The compromise of Silberstein that in rotation there is full drag, and that in translation there is a partial drag, will suit the experimental evidence in hand, but no one seriously supposes that such will be the ultimate result of further experiments.

At the meeting at Kansas, in the unavoidable absence of Gale, a graphic account of the Chicago experiment was given by Watson, who was himself engaged in the work. His description dealt with the body rather than the soul of it.

If two runners start back to back and run with equal speeds in opposite directions round a circular track, they will pass each other again at the starting-point. If one runs faster than the other, there will be a difference. So if light is sent round in opposite ways a many-sided polygon approximating to a circle of radius r , say at the north pole, there will be a time difference

$$\frac{2\pi r}{c-v} - \frac{2\pi r}{c+v} \text{ or } \frac{4\pi r v}{c^2},$$

and this becomes $\frac{4\pi r^2 \omega}{c^2},$

or the area $\times 4\omega/c^2$;

where r is the radius of the track; v , or ωr , the velocity due to earth's rotation. This circulation of light in opposite ways still depends upon the *area*, whatever the shape of the track round which the divided beams circulate. In latitude l there is a factor $\sin l$ to be introduced, and there results a lag in wave-length of $4 \times \text{area} \times \omega \sin l/c^2\lambda$, with an observed value 0.230, as against a calculated value of 0.236, or a verification within three per cent. In place of the crude proof above, there is the relativity proof in Silberstein's "Theory of Relativity" (p. 382), and other proofs may readily be

derived, for it is hard to arrive at any other result by any first-order principle. The result of the experiment is equally gratifying to the relativist and to the classicist. It was pointed out to the writer by K. T. Compton that this uncertainty of 3 per cent. might cover the failure to detect the 5 per cent. slip (20 out of 200 km./sec. or more) which Miller's result might suggest.

As Watson described this heroic experiment, a feeling of disappointment arose that such glorious apparatus had to be dismantled. The pipes (14 in.) were well and truly laid over a large area, and it was necessary to make good joints to get a vacuum, but winter was coming on and frost would have displaced the pipes, so that it is a greater matter for congratulation that this fine experiment should have been carried out, than that the apparatus should have been dismantled and removed.

It is possible to summarise the situation :

<i>For Relativity.</i>	<i>Against Relativity, but for drag and slip.</i>
Mercury perihelion (?). Eclipse results. Spectrum shift.	Miller's experiments on Mount Wilson.
<i>For Relativity or for Stagnant Ether, but against drag and slip.</i>	
Michelson-Gale-Silberstein. Chicago rotation experiment.	

This brief and imperfect record of a difficult subject is written for those who are interested in the situation as it appeared to one who attended the meetings at Kansas City.

Some Properties of the Vitamins.

THE reality of the existence of the three well-known vitamins having been confirmed by numerous careful investigations, attention was directed to their isolation in a pure state, with the ultimate aim of discovering their chemical constitution. At first the work was largely qualitative, but with improvement in the technique of the necessary animal experiments, quantitative investigations became possible, and have led not only to a great increase in our knowledge of these elusive substances, but also to the probable discovery of further members of the series. Whilst undue multiplication of the number of unknown accessory food factors must be deprecated, yet it must be admitted that recent work suggests that there exist besides the orthodox trinity, an antirachitic factor D and an antisterility vitamin E: at the same time, our knowledge of their chemical properties has advanced so considerably, especially in the case of the fat-soluble vitamins A and D, that some of them may soon be justifiably transferred to a place amongst compounds of a similar chemical constitution. Thus the multiplication of vitamins resolves itself into the problem of the identification of substances which are required in metabolism only in minute amounts, and the discovery of which has been delayed until recently owing to difficulties of chemical analysis, and to the fact that they are usually present in the natural food of animals in adequate amount. Similar problems can be found in other branches of biochemistry and metabolism: thus all the amino-acids which make up the protein molecule have not yet probably been isolated, and vitamins are not the only substances which are required in minute quantities—for example, certain elements such as iodine.

Recent investigation has made it clear that the fat-soluble vitamins are present in the unsaponifiable portion of the fat, and that cholesterol can be removed from this fraction without impairing its efficacy. Takahashi and his co-workers have now carried our knowledge a stage further in an elaborate investigation (K. Takahashi, Z. Nakamiya, K. Kawakami, and T. Kitasato, *Scient. Papers, Inst. Phys. and Chem. Res., Tokyo*, 1925, vol. 3, p. 81). Starting with cod-liver oil or green leaves, the unsaponifiable fraction was obtained in a fairly pure condition and the cholesterol removed; some further purification of the product isolated from

the former source was attempted by crystallisation from acetone at -60° to -70° C., followed by distillation at 147° - 150° C. under 0.02-0.03 mm. pressure. These drastic treatments did not appear to destroy the vitamin, but did not effect any great purification: the products obtained from the two sources are somewhat different in composition, that from the oil being the more unsaturated. The yields of the crude material were of the order of 0.1 per cent of the oil and 0.025 per cent of the dried leaves. Tested on animals (rats), about 0.04 mgm. of the crude material or 0.005 mgm. of the purified product sufficed, when given daily to each animal, to promote growth on a diet deficient only in vitamin A.

The Japanese investigators have made a lengthy investigation into the physical and chemical properties of their refined product, which they have labelled 'Biosterin.' It has an absorption band in the ultra-violet, it is soluble in the organic solvents, but is unstable in ether and chloroform, and it is adsorbed by fuller's earth and animal charcoal. It also produces a photo-chemical action upon photographic plates, which the authors suggest, as the result of a series of experiments, is due to the formation of active oxygen from the oxygen of the air over the material: a similar effect was found to be produced, though less markedly, by the cod-liver oil itself, and also, but very feebly, by olive oil. As mentioned above, the vitamin is also stable to heat, in the absence of air. O. Rosenheim and J. C. Drummond (*Biochem. Journ.*, 1925, vol. 19, p. 753) have also shown that the cholesterol free unsaponifiable fraction of cod-liver oil containing the vitamin can be distilled in superheated steam in an atmosphere of nitrogen or in a high vacuum without loss of activity. On the other hand, H. W. Southgate (*ibid.*, p. 733) has found that when the cod-liver oil itself is heated to 200° C. in an atmosphere of carbon dioxide, and maintained at this temperature for varying lengths of time, a slow destruction of both the growth-promoting and the antirachitic factors takes place: the author was unable to show that this destruction was due to the liberation of fatty acids by hydrolysis at the high temperature used.

The stability to heat of these vitamins is of considerable practical importance: thus they are likely to be