SPECIAL ARTICLES

THE DEFLECTION OF LIGHT IN THE SUN'S GRAVITATIONAL FIELD

AMONG the various expeditions sent out to observe the total solar eclipse of May 9, 1929, that of the Potsdam Observatory (Einstein Stiftung) seems to be the only one which obtained photographs suitable for determining the light deflection in the sun's gravitational field. Two instruments were used, but so far only the results of the larger one, a 28-foot horizontal camera combined with a coelostat, have been published. The three observers, Freundlich, von Klüber, von Brunn,[1] claim that these observations (4 plates containing from 17 to 18 star images each) lead to a value of 2.″24 for the deflection of a light ray grazing the sun's edge; a figure that deviates considerably from the results of the 1922 eclipse, and which is in contradiction to Einstein's generalized theory of relativity. In view of the importance and general interest attached to this problem, a few critical remarks on the Potsdam observations and their reduction should not be out of place here[2]:

(1) The accuracy claimed for the Potsdam result is somewhat illusory. A more liberal discussion of the residuals would lead to a probable error of at least $\pm$ 0.″10 (mean error $\pm$ 0.″15), 50 per cent. larger than that given by the observers; but even this does not fully take into account the uncertainty in the adopted scale difference of the plates.

(2) The star field of the 1929 eclipse was unfavorable, for of the 18 stars bright enough to be photographed on the Potsdam plates, 17 were located on one side of the sun and only one star on the other side. That is, we may draw a straight line through the center of the sun such that a single star is on one side of the line and the other 17 stars are on the other side. This extremely unsymmetrical star distribution has the consequence that the light deflections to be determined depend to a high degree on the plate constants used in the reduction; and five such constants for each plate had to be derived from the star measures.

(3) The Potsdam reduction is based on the assumption (in accord with the Einstein theory) that the light deflection is inversely proportional to the star's angular distance from the sun's center. However, the deflections determined by the Potsdam observers are not in accord with this Einsteinian requirement. When the stars are arranged according to their angular distances from the sun's center, a systematic run in the radial components of the residuals is apparent. Among the 6 stars nearest to the sun, 5 have negative residuals, while of the 6 most distant ones 5 have positive residuals. This leads to the conclusion, either that the Potsdam observations are affected by a systematic error, or that the assumption on which the reduction is based is incorrect. Ludendorff[3] has investigated the question of a systematic measuring error; the evidence presented in the following indicates that the fault lies in the scale determination.

(4) In our problem the most important correction to be applied to the differential measures of an eclipse photograph and a photograph of the same (eclipse) group of stars obtained at night for comparison purposes several months before or after the eclipse date is the scale difference between the two plates. The Potsdam observers tried to determine this scale difference independently of the star observations. By means of a collimating telescope, a reseau of fine lines was copied on each of the eclipse plates as well as on the comparison plates, and the observers assumed that the angle corresponding to a reseau interval remained unchanged during the period of from 5 to 7 months which elapsed between the eclipse and the comparison observations. This assumption, however, has no sound foundation. The temperature at the time of the comparison observations (secured at night) was on the average 5° C. lower than during the eclipse, and the tube of the collimating telescope, and in consequence the intervals between the reseau lines recorded on the eclipse and comparison photographs, must have suffered changes due to temperature changes. In fact, the probable temperature effect neglected by the Potsdam observers would be of the right sign and order of magnitude to account for the excess of the observed light deflection over the requirements of the Einstein theory.

(5) Originally the Potsdam expedition in its plans had foreseen the possibility of a change in the collimator-reseau combination. A duplicate horizontal camera was utilized to photograph, at the time of the eclipse, another star field far to one side of the eclipsed sun, and therefore not subject to appreciable Einsteinian deflections; the photographs thus secured, when compared with photographs of this star field obtained at night, to be used in checking or measuring the effects of such a change. Unfortunately the optical qualities of this second telescope were somewhat defective (perhaps because of strains in the objective at the time of the comparison observations), so that photographs of the reseau's straight lines show optical distortion. The observations of the second tele-

[1] Abhandl. d. Preuss. Akad. d. Wissensch., 1931, Math. Phys. Kl. No. 1; *Zeitschr. f. Astrophysik*, 3, 171, 1931.

[2] A fuller account is being published in the *Zeitschrift für Astrophysik*.

[3] *Astron. Nachr.*, 244, 321 and 415, 1932.

scope can therefore not serve their purpose, and without this check the Potsdam scale determination deserves no confidence and should be rejected.

(6) The Potsdam measures can nevertheless be utilized for the study of light deflections, if the scale correction is determined with the other plate corrections from the star observations themselves, a procedure similar to that employed at the 1919 and 1922 eclipses. On account of the unsymmetrical distribution of the stars it is in this case important that all plate constants should be redetermined when the scale value is added as another unknown.[4] A new reduction of the Potsdam measures made by me on this basis leads to a value of:

$$E = 1''.75 \pm 0''.13 \text{ (p.e.)}$$

for the light deflection at the sun's limb, which is in precise agreement with the Einstein theory, as well as in good accord with the earlier observations. The small probable error proves the excellent accuracy of the Potsdam *measures* and entitles this result to carry some weight among the former determinations of light deflection (see Table I).

(7) The residuals from the new solution are much more satisfactory than those of the original reduction. The law of inverse proportionality of the light deflections and the angular distances from the sun's center is now quite well fulfilled; the radial components of the residuals no longer show the systematic run mentioned under (3); and the sum of their squares is reduced to less than half its former amount.

(8) In the Potsdam publication objections are raised against the reduction of the 1922 observations made by the Lick Observatory expedition, and a new reduction of the Lick observations undertaken at Potsdam is mentioned as giving much larger values for E (around 2''.2). Closely examined, the Potsdam formula proposed for the solution of the 1922 observations, *though differing in form,* is equivalent to the one used by the Lick observers. The difference in method lies merely in the fact that the Potsdam observers arbitrarily divided the stars into two groups according to their distances from the sun's center, using the outer stars only for the scale determination, and the inner ones only for the light deflection; whereas the Lick observers, by the method of least squares, derived both unknowns simultaneously from all stars. Check calculations showed in fact that the two methods give practically identical results.

(9) The larger result which the Potsdam observers obtain from the Lick observations is thus not due to any difference in the method, but to an unsuitable choice of weights and the arbitrary exclusion of certain stars. Instead of using the weights established by the observers, the Potsdam authors simplified their calculations by rejecting stars having smaller weights than one eighth of the maximum weight, and giving all other stars equal weights, regardless of the number of plates on which they were measured. But even if this remarkable weighting practice is adhered to, it does not lead to the large value of the light deflection quoted in the Potsdam publication. The latter could only follow (provided there are no mistakes in the

[4] A solution of the Potsdam residuals for Einstein term and scale correction alone was made by Jackson (The Observatory 54, 292, 1931), which led to a value of 1''.98. The considerably smaller result of our complete solution is mainly due to the change in the zero point, which must accompany any alteration in the scale value and the Einstein term.

TABLE I

DETERMINATIONS OF LIGHT DEFLECTION IN THE SUN'S GRAVITATIONAL FIELD

Eclipse	Observing station	Telescope Aper.	Telescope Foc. l.	No. of plates	No. of stars	Light deflection sun's limb	Prob. error	Remarks	Observers
1919 May 29	Sobral	4-in.	19-ft.	7	7	1''.98	±''.12		Dyson, Davidson, Eddington
	Sobral	8	11	16	6–12	(0.86)	± .1	(1)	
	Principe	8	11	2	5	1.61	± .3		
1922 Sept. 21	Wallal	6	10	2	18	1.74	± .3		Chant, Young
	Wallal	5	15	4	62–85	1.72	± .11	(2)	Campbell, Trumpler
		4	5	6	134–143	1.82	± .15	(3)	
	Cordillo-Downs	3	5	2	14	1.77	± .3		Dodwell, Davidson
1929 May 9	Takengon	8	28	4	17–18	1.75	± .13	(4)	Freundlich, v. Klüber, v. Brunn
	Weighted mean					1''.79	±''.06	(5)	

Remarks: (1) Poor focus, rejected by observers; not used for the mean.
(2) If "corrected" for check-field residuals: 2''.05.
(3) If "corrected" for check-field residuals: 1''.71.
(4) New reduction by Trumpler; original reduction by observers: 2''.24.
(5) Weights according to p.e. of individual results; p.e. of mean from sum of weights.

Potsdam numerical calculations) if additional stars, mostly those giving negative residuals, were rejected. Such an arbitary exclusion of observations, however, is against the rules of the theory of errors, and it deprives the result of any value.

(10) In the publication of the 15-foot camera observations, secured by the Lick expedition of 1922, attention was drawn[5] to a run in the residuals of the check star field (photographed on the nights before and after the eclipse). Since the origin and reality of these small residuals are quite doubtful, the observers based their final result (1.″72) on the observed (uncorrected) star displacements D_1. Freundlich, von Klüber, and von Brunn, on the other hand, give preference to the figure 2.″05 obtained from the star displacements D_2 which are "corrected" for these uncertain residuals of the check field. It is true that this choice is a matter of personal judgment, but whatever the choice, the same procedure should be employed for both pairs of instruments used by the Lick expedition. The adoption of the Potsdam view-point would require that the observations secured with the Lick pair of 5-foot cameras[6] be similarly "corrected" for the check-field residuals, and this would lead to a slightly smaller value (1.″71). The mean of the results given by the two pairs of instruments would then be 1.″9, which still agrees with Einstein's prediction within the limits of permissible observational error.

SUMMARY

The scale determination for the 28-foot camera, on which the published result of the Potsdam expedition is based, is unsatisfactory and should be rejected. A new reduction of the Potsdam measures, in which the scale correction is determined from the star observations, yields a result of $E = 1.''75 \pm 0.''13$ for the light deflection at the sun's limb, and considerably reduces the residuals of the observations. The objections of the Potsdam observers against the reduction of the 1922 observations are not valid, and there is no reason to change the results published by the Lick observers. The various measures of light deflection at the sun's edge thus far available are listed in the following table; their weighted mean is $1.''79 \pm .''06$.

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NORMAL TISSUES AS A POSSIBLE SOURCE OF INHIBITOR FOR TUMORS[1]

THE presence of an inhibitor associated with the causative agent of a chicken tumor has been reported in recent communications. While the tumor agent is more or less species specific the inhibitor from the sarcoma has been found to affect definitely a transplanted sarcoma of mice. The results of these observations and others on the properties of the causative agent led to the suggestion that the mechanism involved in the induction and growth of the chicken tumor may be an unbalanced but similar mechanism to that which controls growth and differentiation of normal tissues. This conception led to attempts to separate the hypothetical stimulating and retarding factors from active normal tissues. We have discussed elsewhere the limited evidence indicating the possibility of inducing malignant transformation by means of the growth-augmenting factor. The present paper is a report of experiments which suggest that an inhibiting factor may be extracted from certain normal tissues.

The inhibitor or balancing factor might be expected to occur where there is a greater concentration of the stimulator. Therefore we have used active tissues as the source of our test materials. Preliminary experiments with extracts of whole fresh embryos and placenta of the mouse, treated in the same way as the chicken tumor extract, *i.e.*, heated to 55° C. for 30 minutes, had little influence on either transplantable carcinoma or sarcoma of the mouse. Profiting by the experiments with chickens, where the tumor desiccate yielded more definite amounts of the inhibitor, we changed the method to the following:

Method: The test tissues consisted principally of placenta, whole embryo, embryo skin and skinless embryo of the mouse. The tissues were macerated, spread in thin layers in a sterile dish, frozen and dried *in vacuo*. These desiccates were ground to a fine powder, extracted with a small amount of water, centrifuged and the supernatant fluid tested on tumors. The carcinoma used for inoculation was cut up into the usual size grafts and part of these immersed in the suspension made from the dried tissues and part in normal salt solution for controls. Usually two or three nicks were made in the grafts to give a greater area of exposure to the fluids. The time of contact allowed was only that required to load the grafts into trocars for inoculation. With the Crocker sarcoma 180 a suspension of the cells was made by forcing the tumor through a fine grill and 1 cc of the cells suspended in 3 cc of salt solution. This suspension was added to an equal amount of the tissue extract and 0.05 cc injected immediately into mice. For the controls the suspensions were diluted in the same proportion with Ringer's solution. The treated tumor was inoculated into one groin and the control into the other. Additional mice were inoculated with

[5] *L. O. Bull.*, 11, 54, 1923.
[6] *L. O. Bull.*, 13, 130, 1928.
[1] From the Laboratories of the Rockefeller Institute for Medical Research.