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POURQUOI N'A-T-ON PAS ENCORE PROUVÉ L'EFFET RELATIVISTE DE DÉPLACEMENT VERS LE ROUGE ?

par Erwin Finlay FREUNDLICH

Precisely 50 years have passed since EINSTEIN, formulating the principles on which a general theory of relativity had to be founded, realized that from an assumed equivalence of the effects produced by a gravitational field and by accelerated motions, it necessarily had to follow that all spectral lines in the solar spectrum revealed a general red shift : $\Delta\lambda = \lambda \cdot \Delta\psi/c^2$; here $\Delta\psi$ denotes the difference of the gravitational potential on the surface of the Sun and Earth respectively and c the velocity of light. Hence all Fraunhofer lines should appear shifted by an amount

$$\frac{\Delta\lambda}{\lambda} = 2,12 \times 10^{-6}$$

corresponding to an apparent Doppler effect of $+ 0,636$ km/sec . This general red shift must be shown by the light from whichever point on the Sun's disc it may be emitted. The problem of proving the existence of this effect has not yet been satisfactorily solved. Initially Einstein's postulate met with great scepticism. At that time, no detailed physical theory of the solar atmosphere existed. It was believed that in the layers from which the spectral lines originate high pressures prevailed, and since red shifts of the lines quite definitely made their appearance, pressure effects were thought to be responsible for the observed red shifts.

This sceptical attitude however changed into a much optimistic acceptance of the relativistic postulate when around 1920 Saha's theory of the solar spectrum proved that very low pressure values were to be expected in the highly ionized atmosphere of the Sun, but chiefly when the success of the British solar-eclipse expedition in 1919 seemed to confirm Einstein's second postulate concerning the deflection of a light beam in the gravitational field of the Sun.

Although from the outset the comparison of the solar wave lengths with those emitted by terrestrial light sources never revealed shifts of the predicted amount, constant over the Sun's disc, the existence of the general relativistic red shift was taken for granted. Since the actually observed red shifts are in the centre of the solar disc usually considerably smaller, usually less than half the theoretically predicted value of $2,12 \times 10^{-6}$, and since in addition the values increase steeply with approach to the limb of the Sun even surpassing the expected value, the contradiction against expectation was met by assuming that radial currents in the Sun's atmosphere, producing predominantly small negative Doppler-effects, are responsible for the reductions of observed red shifts. As to the rise near the limb, it became necessary to introduce in addition an otherwise, unexplainable "limb effect".

On this foundation is based St John's proof that the general red shift predicted by the general theory of relativity may be considered as supported by solar observations (1927). He accumulated for this purpose a vast amount of observational material : 1537 lines measured at the centre of the Sun's disc ; 133 lines measured near the limb, however no observations at intermediate positions on the disc. The existence of the general red shift was taken for granted, its value subtracted from the observed line-displacements, and the remaining shifts then discussed from the point of view that Doppler shifts produced by radial currents - different for different depths from which each line was emerging - and a limb effect were responsible for the observed shifts. Thus, the radial current theory was developped to support the observed line displacements. It need not to be emphasized that the proof of the existence of an effect of such fondamental importance as the relativistic red shift asks for a safer foundation. Not only the existence and character of the radial currents in the atmosphere are still open to criticism, but in particular the now safely established fact that the red shift surpasses at the limb the theoretical predicted value proves that "the Einstein effect plus radial currents do not suffice to explain the observations". There are obviously causes other than Doppler effects and the relativistic shift which affect the positions of solar lines. A very much more detailed and accurate analysis of the solar spectrum is needed if the existence of the relativistic red shift is to be safely established.

Such an analysis began shortly after ST JOHN had published his apparently conclusive results, when without any reference to a terrestrial light source observations in Potzdam investigated the pattern of differential solar wave lengths along the disc from centre to limb. It came to light that in whatever direction one moves from the centre of the Sun towards the limb all lines reveal steadily increasing wave lengths. Near the centre the increase is slow, becomes however steep as soon as $\sin\theta > 0,7$ (θ = the angle between line of sight and the solar radius to the point where the line of sight cuts the solar surface). Along all radii from the centre to the limb the increase is the same. The pattern appears completely symmetrical, following closely a law of the form $\alpha + \beta \sec \theta$ (α , β constants). If radial currents were responsible for the observed reduction of the red shift from its predicted constant value, the increase towards the limb should follow a law similar to : $\Delta\lambda_{obs.} = \Delta\lambda_{rel.} - \Delta\lambda_{rad.cur.} \cos \theta$.

At the limb all observed shifts should converge towards the relativistic value of : $\frac{\Delta\lambda}{\lambda} = 2{,}12 \times 10^{-6}$.

This is quite definitely not the case.

Hence the character of this internal pattern, i. e. of the steep increase of the red shift from center to limb, had to be cleared up. This new chapter in the history of the problem began when in 1958 Miss M. ADAM, using the modern solar equipment in Oxford, revived the whole problem. The course of the red shift for 14 selected solar lines was followed along a radius of the Sun's disc from the center till $\sin \theta = 0{,}984$, and measured at 7 points. The observations are perfectly represented by the formula :

$$\Delta\lambda_r = X_r + Y.f(\theta) \quad .$$

Here the X_r denotes the observed red shifts at the Sun's center for the line " r " ; the values change from line to line in an unaccountable manner and range from $-3{,}10^{-3}$ Å to $+6{,}10^{-3}$ Å . The theory asks for a constant shift of 13×10^{-3} Å for this special group of lines. Y is the limb effect, practically the same for all lines, equal to $(2{,}04 \pm 0{,}04) \times 10^{-3}$ Å . Up to date, we are unable to answer the questions which now arise :

a. What is the origin and nature of the individual central shifts X_r ?

b. What is the origin of the second term, with the factor Y ? Is it the outcome of a physical effect depending on conditions in the solar atmosphere, or an universal effect affecting the positions of all Fraunhofer lines ?

c. Is the constant relativistic red shift hidden in this pattern to be disentangled from it ?

As long as radial currents in the solar atmosphere were considered sufficient to provide a satisfactory model of its internal structure, the fact that at the limb the observed red shifts surpass the predicted relativistic value seemed quite definitely to frustrate all hopes of a satisfactory explanation of the observations. However, during the last years, it has been realized that the granulation on the Sun's surface indicates the existence of turbulence in the Sun's atmosphere ; thus, the conditions in the atmosphere from which the spectral lines of the Sun emerge might be much more complex than hitherto considered and the question (c) above needs further careful consideration. So far the influence of turbulence upon the profiles of some faint solar lines has been studied. Figures showing the representation of the changing profile for the iron line Fe_I, $\lambda = 5295$ Å, in the centre of the disc, $\cos\theta = 1{,}00$ and for $\cos\theta = 0{,}35$ are given in the article of John H. WADDELL ([1]). The best representation is obtained accepting an anisotropic turbulence-model with the random turbulent velocities : $\xi_{rad} = 1{,}8$ km/sec , $\xi_{tan} = 3{,}0$ km/sec . This research has only just started and so the model used may not be the final solution. But it reveals already what values of the turbulent velocities may have to be considered. How the positions of the observed Fraunhofer lines will be affected, whether in particular the "limb effect" will find an explanation is still an open question.

In any case, as long as no final and satisfactory model of the solar atmosphere exists, we can not hope to be able to give a final answer whether the Fraunhofer lines reveal the general red shift : $\Delta\lambda/\lambda = 2{,}12 \times 10^{-6}$. Had the development of the problem first yielded a complete picture of the conditions under which the Fraunhofer lines are emitted, say, from an extensive study based purely on differential measurements of line-displacements, $\lambda_{\theta=0} - \lambda_\theta$, without any reference to terrestrial light sources, the universal character of the relativistic red shift would have shown up as soon as terrestriel wave lengths had been introduced, as a general unmistakable shift of the zero point, true to its fundamental character. As it is, if the relativistic red shift does exist, it must be deeply hidden in the complex pattern of the line displacements revealed by the solar lines on the Sun's disc.

At present no easy way seems to offer itself to disentangle the obscure situation. It appears indeed more likely that purely terrestrial laboratory observations, based on the lately discovered Mössbauer-effect which permits the determination of extremely small shifts of lines of the order of $\Delta\lambda/\lambda = 10^{-12}$ to 10^{-15}, instead of 10^{-7} Å in the case of astronomical observations, will yield the final answer to the physical problem under consideration. The astronomical research on this line will have to concentrate primarily on the solar problem of the structure of the solar atmosphere.

([1]) WADDELL (John H.). - Study of solar turbulence based on profiles of weak Fraunhofer lines, Astrophys. J., t. 127, 1958, n° 2, p. 284-301.