genetic factors, while the cytological study of sex was closely connected with the chromosome-theory of Mendelian heredity. It therefore appears rather tempting to apply the quantitative views of sexual differentiation to the theory of heredity in general. Recently an attempt has been made by the

writer in "Die quantitativen Grundlagen von Vererbung und Artbildung" (Berlin, J. Springer, 1920) to attack the problem of the physiology of heredity from this point of view. A discussion of this would, however, be beyond the scope of this contribution.

Further Remarks on Relativity.¹

By SIR OLIVER LODGE, F.R.S.

III.

Changes of Frequency.

ACCORDING to the usual presentation of relativity, clocks appear to go slow to a relatively moving observer; quite irrespective of any Doppler effect, which can readily be allowed for. Their rate would have to be multiplied by the fraction $1/\beta$ or $\sqrt{1-u^2/c^2}$; which means that a clock on the sun seen from the earth, say on December 31 or July 1 when the motion is exactly transverse, would lose one second in two hundred million, or about sixteen seconds per century.

But, for testing purposes, we cannot change the motion appreciably, and so we cannot hope to tell if the clock would seem to go quicker if we stopped. Reversal of motion, even if it could be accomplished, would be no good; the difference to be observed—unlike the Doppler effect—is between motion and rest, or between rapid motion and slow, not between *plus* and *minus* motion. If we had a clock which we could fix at relative rest to ourselves, and yet be sure that it kept time with the one we were observing on some relatively moving body, the comparison might be made. And the revolution or vibration of a radiating atom, (a) on earth, and (b) on sun or star, appears to satisfy the conditions. If source and observer were moving together, there would be compensation; but if either was moving without the other, there should be an effect, such as by long accumulation might be detected. The Mercury effect allowed accumulation for a century or more. The spectrum effect does not allow any accumulation; whatever can be seen there must be seen instantly, it must depend on what happens in a single period. It is true that a certain train of waves is needed for visibility, and some succession is necessary for interference; but so short is the series required for interference that position in the spectrum is practically dependent on individual wave-length.

The value of u^2 for the earth's orbit, considered circular, is equal to the sun's gravitational potential at the earth's distance under the inverse square law, say $-V$; or twice that potential under the direct distance or centrifugal-force law. Hence the slowness to be expected, $\sqrt{1-u^2/c^2}$, may be written either $1+V/2c^2$ or $1+V/c^2$; and the second term is the displacement towards the red which is being looked for. Only, of course, it is being looked for where the potential is strongest, viz. close to the sun; for there it is two hundred times stronger than in the neighbourhood of the

earth (the radius of the earth's orbit being two hundred times the radius of the sun). It seems, however, that a small fraction of the gravitational effect ought to be produced as the result of the earth's motion, even if the sun were nothing but a central source of light.

The occurrence of the factor 2 is curious, and corresponds with a similar factor in the ray-bending calculation. But I do not now discuss it, because a spectral shift due to transverse motion is doubtful. Space-measuring rods shrink, it is true, but in the direction of motion, not in the sun's direction; so the measured velocity of light from the sun would be constant without any time-correction. Yet it is not easy to see how a clock-discrepancy can be dependent on the direction of motion, apart from the ordinary allowance for light-speed.

Changes of Inertia and Weight.

That an electric charge possesses the fundamental material quality of inertia, by reason of the magnetic field which inevitably is generated when it moves, was first calculated by Sir J. J. Thomson so long ago as 1881. That this electrical inertia is a function of speed, so that as the speed of light is approached it ought to undergo a rapid increase of value, was predicted, and its amount reckoned, by both J. J. Thomson and Oliver Heaviside. That the facts of observation were in accord with the prediction, was verified, first by Kaufmann and then by others; while that this subordinate dependence of inertia on speed applies even to neutral atoms of matter, is a consequence of the fairly ascertained electrical nature of their constitution. On the theory of relativity the variation of inertia appears to follow, without any electrical theory at all, as a result of changing the frame of reference to moving axes. The additional mass corresponds to the kinetic energy of the moving matter divided by c^2 . Which suggests that the whole mass is probably a demonstration and a result of fine-grained ætherial rotational energy with velocity c .

It is legitimate, anyhow, to assume as a working hypothesis that the mass of a body is not really constant, but that at the speed u it becomes $m = \beta m_0$ or $m_0/\sqrt{1-u^2/c^2}$.

The speed necessary to display this effect is usually attained only by electrons and positive nuclei in a vacuum tube, or by aid of spontaneous radio-activity; but the refinements of astronomy are so great that the planet Mercury is moving fast enough to exhibit some result dependent on

¹ Continued from p. 751.

this variation of inertia, if it were allowed to accumulate for a century. If the speed were constant it could not be detected; but the speed is not constant. The orbit is elliptical, for one thing; and the solar system is in motion, for another. Sometimes, therefore, the solar drift will be added to the orbital speed of Mercury, sometimes it will be subtracted from it.

Here then is a definite problem: to trace the consequences of this variation of inertia on the form or details of its orbit; and this problem I attacked in the *Philosophical Magazine* for August, 1917, and found that it must lead to a cumulative apsidal revolution unless there were some compensating cause. The paper was followed up by Prof. Eddington in September and October 1917 and June 1918, by Mr. G. W. Walker in April 1918, and by myself again in December 1917 and February 1918.

We found that if the solar drift were sufficient, both in magnitude and in direction, to give the proper value for the perihelion progress of both Mercury and Mars—as it easily might be—a smaller effect could not be denied to some of the other inner planets; and there would be accompanying small eccentricity changes, not corresponding with observation. The best solar drift is one with the speed $1.7 \times 10^{-4} c$, and longitude 173° , for its component in plane of ecliptic. This will suit Mercury, both for apsidal revolution and for eccentricity. The perturbations that ought theoretically thus to be caused in the other inner planets are tabulated below; and, to compare with these calculated values, the table gives also the actual estimated or observed outstanding secular variations per century, both for the perihelion progress, $d\omega$, and for the change of eccentricity, de . (See *Phil. Mag.*, February, 1918, pp. 148 and 154.)

Outstanding Perturbations per Century.

Solar drift assumed: Speed, $1.7 \times$ earth's orbital vel. Direction, 173° long. and 0° lat.	Calculated.		Observed.	
	$d\omega$	de	$d\omega$	de
	"	"	"	"
Mercury	+8.34	-0.91	+8.48	-0.88
Venus	+1.46	+1.52	-0.05	+0.21
Earth	+1.04	+0.32	+0.10	+0.02
Mars	-0.12	-0.46	+0.75	+0.29

The discrepancies between theory and practical estimate, though small, are considered to be beyond anything that can reasonably be attributed to errors of modern observation; and if that is the final verdict of astronomers, after reconsideration of the figures, it becomes a question what is the compensating cause that prevents fluctuations of inertia from taking effect. The only cause that has suggested itself is a variation in the Newtonian gravitation constant, due to its being a function of velocity; so that weight is modified, somewhat in the same sort of way as electrostatic forces are modified, by rapid motion. (*Phil. Mag.*, February, 1918, p. 156.)

Prof. Eddington has now agreed (see his admir-

able book, "Space, Time, and Gravitation," p. 125) that the result of the whole discussion is to prove that gravitation has "joined the conspiracy," and has succeeded in concealing any effect of uniform motion.

But, on Eddington's improved theory (*Phil. Mag.*, October, 1917), it achieves this result in an odd way, and apparently does not sustain Einstein's "Equivalence" thesis, that inertial mass and gravitational mass are the same in all circumstances; or, briefly, that weight is always proportional to mass. Some caution is here required; for the proportionality of weight and inertia seems to be interfered with at high speeds. Their product, not their ratio, appears to be involved in a planetary perturbation, regarded from the point of view of the electrical theory of matter; and hence, if one increases, the other must decrease.

Galileo's experiment on the Tower of Pisa, roughly, and Newton's pendulum determinations, more exactly, established the proportionality of mass and weight; and recently Prof. Eötvös, followed by Prof. Zeeman, has confirmed Newton's conclusion to a high degree of accuracy, so far as ordinary circumstances and slow motions are concerned. (See the excellent new edition of Clerk Maxwell's wonderful little book, "Matter and Motion," brought out last year by Sir Joseph Larmor (S.P.C.K.), pp. 34 and 143.) But the astronomical evidence cited above seems to require that the Newtonian gravitational constant shall diminish at high speeds, being multiplied by the factor $1 - u^2/c^2$. Only thus can it compensate the inevitable increase of inertia $(1 - u^2/c^2)^{-1}$; at least if the increase of inertia sustains its full increment of weight. If the increase of inertia due to motion is *not* subject to gravity, then $\sqrt{1 - u^2/c^2}$ will suffice as the factor of the gravitation constant. (*Phil. Mag.*, February, 1918, pp. 143, 145, 155.)

Assuming that so it will turn out, after further detailed scrutiny, it is clear that weight is affected by high-speed locomotion. For the increased mass of a fast-revolving planet would by itself undoubtedly cause a minute apsidal progression sufficient to be observed; and the fact that for several of the inner planets the outstanding perturbations are less than the calculated, shows that compensation must somehow occur. It is to be hoped that the peculiar nature of the compensation, here suggested, may ultimately throw light on the gravitational structure of the æther. Meanwhile, unless some error is detected, it appears in conflict with the universal proportionality of mass and weight.

We shall now proceed to a few remarks on points connected with the more general theory of relativity.

ERRATUM.—In the first article of the present series (*NATURE*, August 4), on p. 718, 1st col., l. 6 of 2nd para., *delete* the words "in v if it is opposed to u "; and *substitute* "when the observer reverses his motion."

(To be continued.)