(*B*) and (*C*) is purely a matter of taste. There is no physical criterion as yet available to decide between them. It is true that the systems (*B*) and (*C*) do not satisfy MACH's postulate that inertia must be traceable to a material source. But this postulate is a purely metaphysical one, and has no physical foundation whatever. It appears to me to be the last remnant of the desire for a purely *mechanical* interpretation of nature, which logically and historically is based on the belief in forces at a distance, and the impossibility of which has been so clearly demonstrated by EINSTEIN in his Leiden address.

The three systems differ however in their physical consequences at large distances, and an experimental discrimination between them may be possible in the future. The decision between (*B*) on the one, and (*A*) and (*C*) on the other hand may be brought about by the study of systematic radial motions of spiral nebulae [1]). The distinction between (*A*) and (*C*) is more difficult, since they both have $g_{44} = 1$, and differ only in the g_{ij} with i and j different from 4, the values of which at great distances it is not so easy to ascertain. The decision between these two systems must, I fear, for a long time be left to personal predilection.

infinity; two straight lines have only one (and not two) point of intersection, which may be situated at infinity; if we go to infinity along one branch of a hyperbola, we return along the other branch on the other (and not on the same) side of the asymptote. All these are properties of the elliptical as contrasted with the spherical space. The spherical is only a quite unnecessary reduplication of the elliptical one.

[1]) See DE SITTER, l. c. pp. 27—28. At that time (1917) the radial velocities of only three spirals were known, of which one was negative; the mean being + 600 *km/sec.* Now the radial velocities of 25 spirals are known (see Mount Wilson Publications, Nr. 161, p. 19) of which only three are negative, the mean being + 560 *km/sec* (or + 677 *km/sec* if the four brightest are omitted). The system (*B*) requires a (spurious) positive radial velocity for distant objects.

Physics. — *"The Mechanism of the Automatic Current Interrupter".* By Prof. J. K. A. WERTHEIM SALOMONSON.

(Communicated at the meeting of November 27, 1920).

The mechanism of the automatic current interrupter as represented by HELMHOLTZ's tuningfork interrupter, by NEEFF-WAGNER's hammer-break, and by the ordinary electric bell, has not yet been explained in an entirely satisfactory way. Lord RAYLEIGH was the first to give an explanation, without, however, entering into details. Later on its mechanism was studied by LIPPMANN, DVORAK, GUILLET, BOUASSE and others although no new points of view were opened. In this paper I intend to submit a few considerations on this subject, principally based on a research into the attraction by the electromagnet on the armature during the working of the apparatus. As an indicator for the attraction I used the number of lines of force passing through the armature at each moment. These were measured by an oscillographic method. This might have been done by the new ABRAHAM-rheograph, but as I did not possess this instrument I employed DEGUISNE's method, described in the Physikalische Zeitschrift 1910, p. 513. The results of this method were compared with those obtained by a new method, which I shall describe in an appendix to this paper.

The interrupter used in my experiments has a horizontal horseshoe magnet. The cores turned from a solid bar of swedish iron completely bored and slit lengthways, have a length of 5 cm and a diameter of 1 cm. They are screwed at a distance of 3.2 cm from each other into a yoke of 1.4 cm² transverse section, and are each wound with 200 turns of well insulated copper wire of 1.2 ohm resistance each. The armature measured 1.2 × 0.75 × 4.4 cm. It is screwed to a strong steel spring of 0.12 × 1.0 cm. with a free length of 1.3 cm. Into the other end of the armature a brass bar 0.4 cm. in diameter and 5 cm. in length was fixed, on which, if desired, a small copper weight could be screwed. It was generally used without weight and then made about 47 complete vibrations per second, the platinum contact being so adjusted as to make and break the current during one half of the periodic time. The armature was wound in its middle part with 40 turns of copper wire, the ends of which were connected by means of two large spiral windings with a pair of fixed terminals, in such a way as not to hamper its vibrations. If the interrupter is connected into a circuit with an inductionless ballastresistance of about 1 Ohm and with two accumulator cells, the vibrations have an amplitude such as to render the distance of the armature from the cores taken together, variable from 2 millimeters to 7.6 millimeters. Without current the sum of the airgaps has a length of 4.8 millimeter. The selfinduction of the electromagnet, which of course is not constant, has during the passage of the current a mean value of about 9.3 millihenry.

Whilst the interrupter was in action, oscillograms were taken of the current through the electromagnet and at the same time the magnetic density in the armature was oscillographically recorded. For the current a high frequency DUDDELL oscillograph of the Cambridge Instrument Cy was used, whilst the magnetic density was recorded with a SIEMENS and HALSKE oscillograph, or with a string galvanometer. On the oscillographic records time marks of 0.01 second were inscribed. For the stringgalvanometer records 0.001 second marks were used.

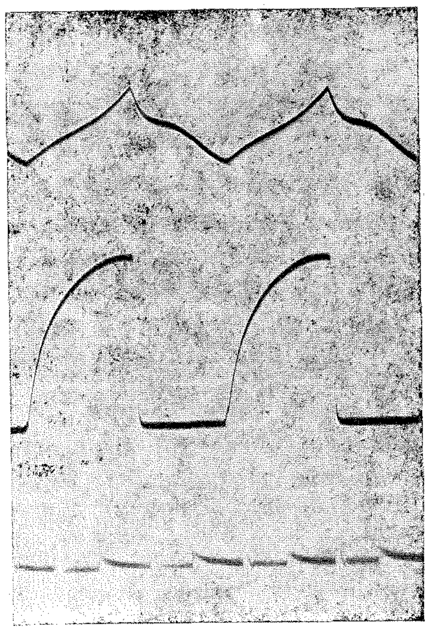

Fig. 1.

In this way curves, as given in fig. 1, were obtained (2 times enlargement of the original negative) with the oscillograph, or as in fig. 7 with the stringgalvanometer.

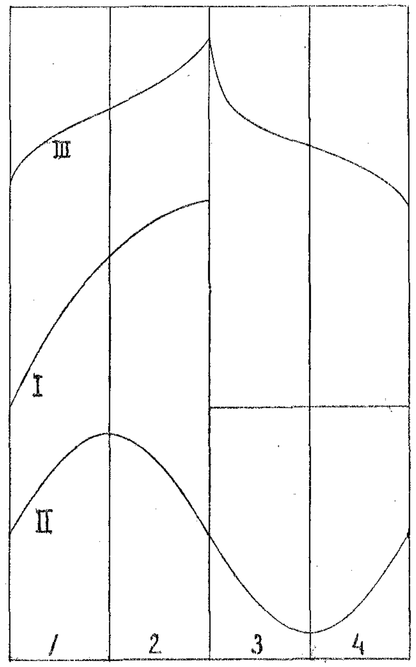

Fig. 2.

We can divide one complete period of the interrupter into 4 nearly equal parts. The two first quarter periods represent the time during which the circuit is closed, the two last ones the break period. During the 2nd and 3rd quarter period the armature moves towards the cores; during the 1st and 4th quarter period in an opposite direction. We know that the number of lines of force passing through the armature determines the force with which it is attracted by the electromagnet. We may even say that this attraction is very nearly proportional to the square of that number of lines of force.

Our curves show that the attraction during the second quarter period is very much greater than during the first. This fact was pointed out by Lord RAYLEIGH and has practically formed the basis of all later communications on this subject. But at the same time we see that during the 3rd quarter period, the current being broken, a strong attractive force still exists, which is notably stronger than the attraction which during the 4th quarter period works against the movement of the armature. Even when the interrupter works under very different conditions as to frequency, current-strength etc. this fact remains unchanged. We may say that the attraction during any part of the movement of the armature towards the pole pieces, greatly exceeds the attractive force in any point during its course away from the electromagnet. Consequently there is no need for any retarding device for making the current with respect to the movement of the armature — as suggested by Lord RAYLEIGH — in order to improve the working of the interrupter. Probably such a device would not only be inconvenient, but would hamper the working of the apparatus.

Can we explain the curve for the attraction? For the ascending part this is certainly possible. We can even calculate it approximately. We first suppose the selfinduction to be constant during the make period. Applying the wellknown formula of HELMHOLTZ:

$$I = \frac{E}{R}\left(1 - e^{-\frac{R}{L}t}\right)$$

we compute the current strength in the magnet at every moment. The current strength being known we try to calculate the number of lines of force through the armature, assuming it to be proportional to the current strength and inversely proportional to the length of the airgap. We may do this as, practically, the total reluctance in the magnetic circuit is to be looked for in the airgaps. With small magnetizing forces the permeability of the iron is so great that this assumption is permittable. As an example we may take the moment just before the breaking of the current. Using HELMHOLTZ's formula and supplying the real value of the constants, we find $I = 1.13$ ampere, whilst from the oscillographic record we find $I = 1.17$ ampere. This makes the magnetising force: $0.4\pi \times 400 \times 1.17 = 590$. As the airgap has a length of 0.48 cm we get $590 \times 0.48 = 1225$ lines of force through 1 cm² air-section. These lines start from the pole pieces, which have a surface of 0.7 cm²; hence we find for the magnetic density in the iron not more than 1750 lines per cm². This means that we may expect a permeability μ of the order of 3000. Taking $\mu = 3000$ we find that to force 1225 lines through 16.4 cm of iron of a section of 0.7 cm², not quite 5 ampere turns are needed. Consequently we have an error of not more than 1%, if we consider the airgap only and disregard the ironpath.

In order to calculate the number of lines during the make-period, we assume that the armature vibrates in such a way as to vary the length of the airgaps periodically, according to the expression $a + b \sin 2\pi nt$. Then we get as an approximate expression for the number of lines of force:

$$B = \frac{0.4\pi N \frac{E}{R}\left(1 - e^{-\frac{R}{L}}\right)}{a + b \sin 2\pi nt} \quad \text{for} \quad 0 < t < {}^1/_2\,\pi$$

in which N is the number of turns of the magnetising coils, E the voltage of the galvanic battery, R the resistance of the circuit, L the mean selfinduction, n the frequency of the interruptions, a the mean length of the air-path, and b half the amplitude of the armature. If we put in this formula the value already given for each of the constants, we get as a result the curves in fig. 3, where I represents the current strength, II the length of the airgap and III the number of lines of force during the make period. If this last curve be

compared with the ascending part in the oscillographic record, we see that they correspond fairly well. The constructed curve shows

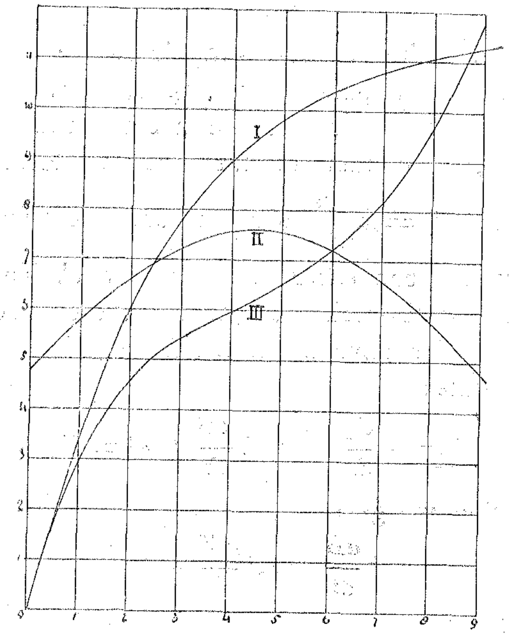

Fig. 3.

a somewhat more rapid ascent in its first part, and also some difference in the last part. But this can readily be explained. If we had calculated the current strength, taking into account that the selfinduction was greater at the beginning and at the end of the make period and smaller in the middle, the curves might have agreed better numerically: theoretically this point is of little or no interest.

The descending part of the curve, which embraces the two last quarter periods, represents the magnetic attraction during the break period. A quantitative explanation is as yet not possible, though qualitatively there seems to be no difficulty. We know that the less reluctance there is in the magnetic circuit, the longer will an electromagnet keep its magnetism after breaking the current. Immediately after breaking the current the air-path is rather large and consequently the reluctance is great and the magnetism disappears rapidly. As the armature approaches the core, the magnetic circuit improves and the magnetism disappears more slowly. The slope of the curve is indeed least at the end of the 3rd quarter period. From then to the end of the 4th quarter period the reluctance grows and the descent becomes more rapid again, becoming nearly as fast as in the commencement of the 3rd quarter period, though not quite, as at that moment the direct action of the magnetomotive force is taken away.

New method for making oscillographic records of the number of lines of force.

If we desire to make an oscillographic record of the number of lines of force in an iron path or an airgap, a few insulated copper-windings are laid round the iron or a small coil is placed in the air gap. When the number of the lines of forces B varies, an electromotive force $V = k\dfrac{dB}{dt}$ is generated. The terminals of the coil are connected with a condenser of a capacity C. This takes up a charge $q = VC$ and through the coil and the connecting wires with a total resistance r we have a current i.

Now we can state:

$$i = -\frac{dq}{dt} \quad \text{and} \quad k\frac{dB}{dt} + ri = V \quad \ldots\ldots \quad (1)$$

After substitution we get:

$$k\frac{dB}{dt} = rC\frac{dV}{dt} + V$$

and putting $\dfrac{rC}{k} = A$:

$$\frac{dB}{dt} = A\left(\frac{dV}{dt} + \frac{1}{rC}V\right) \quad \ldots\ldots \quad (2)$$

which gives after integration:

$$B = AV + \frac{A}{rC}\int V\,dt + Konst. \quad \ldots\ldots \quad (3)$$

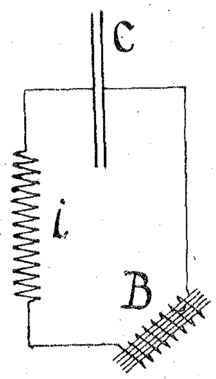

Fig. 4.

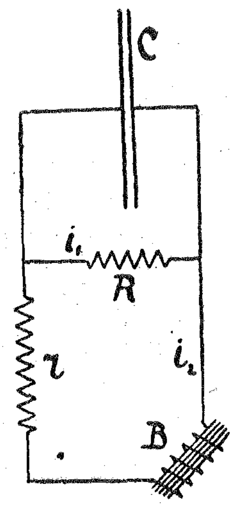

Fig. 5.

If we may disregard the expression $\dfrac{1}{rC}V$ with respect to $\dfrac{dV}{dt}$ the electromotive force V is proportional to the magnetic induction. Generally it will be impossible to measure V with an oscillographic electrostatic instrument. But we can use a galvanometric oscillograph at the terminals of C. We shall then get the connections shown in fig. 5 and the differential equations become:

$$-\frac{dq}{dt} = i_1 + i_2 \quad \text{and} \quad k\frac{dB}{dt} + ri_1 = Ri_2 \quad \ldots \quad (4)$$

We eliminate i_1 and get

$$\frac{dB}{dt} = A\left\{\frac{dV}{dt} + \left(\frac{1}{RC} + \frac{1}{rC}\right)V\right\} \quad \ldots\ldots \quad (5)$$

in which $A = \dfrac{rC}{k}$. After integration this becomes:

$$B = AV + A\left(\frac{1}{RC} + \frac{1}{rC}\right)\int V\,dt + Konst. \quad \ldots \quad (6)$$

We find a linear expression connecting B and V if the integral in (6) need not be considered. This is allowed if both RC and rC are very large and if also the frequency per second is high enough. With a periodic change of B, which might be represented by a FOURIER series, the value for the integral during one period $= 0$. We have only to examine its value during one period. With a frequency of 50 per second and time constants CR and Cr of 0.2 second each we get for a potential curve as represented by the

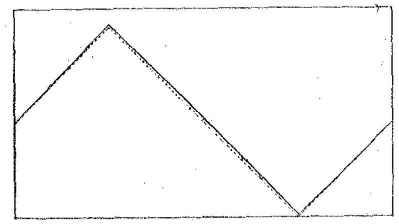

Fig. 6.

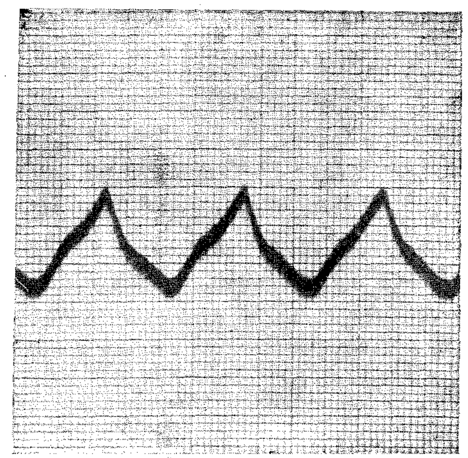

Fig 7.

broken-line curve in fig. 6 the correction indicated by the full-line curve. At the starting point and the end the correction is zero. At the highest point with an ordinate a we get a correction:

$$a(5+5):2\times 200 = {}^{1}/_{40}\,a, \text{ or } 2.5\,\%$$

of the maximum ordinate.

In my experiments I used a condenser of 2 mikrofarad, R and r being 10^6 Ohm each. The oscillographic record was made with a stringgalvanometer. Fig. 7 gives an example of the curves obtained in this way.

Zoology. — *"The wing-design of mimetic butterflies"*. By Prof. J. F. VAN BEMMELEN.

(Communicated at the meeting of Nov. 27, 1920).

In a paper: On the phylogenetic significance of the wing-markings of Rhopalocera, read before the meeting of the second International Entomological Congress at Oxford in **1912**, I made the casual remark that "while inspecting the series of butterflies in search for specimens showing the primitive colour-pattern, I was greatly impressed by the considerable percentage of mimetic forms among my harvest. So the idea occurred to me that perhaps Mimetism might, at least to a certain degree and for a limited number of cases, be explained by supposing the resemblance between two or more non-related forms to have started at an early period, when the ancestral types of different butterfly-families looked more like each other than nowadays, on account of the primitive colour-pattern common to them all".

Since those days I have tried to clear and widen my ideas about the real character of the primitive colour-pattern, especially by a detailed analysis of the wing-design in original forms such as the Hepialids, and by its comparison to the pattern of the body. These investigations have led me to a modified conception of primitiveness in pattern: the occurrence of sets of uniform spots, regularly arranged in rows between the wing-veins, and spread over the entire wing-surface, appearing to me as a still more original condition than the concentration of the markings in the shape of a stripe along the middle-line of the internervural cells. But this does not in the least weaken my conviction, that this latter arrangement has retained a considerable amount of primitiveness also, and that its origin lies far beyond the beginnings of genera, families, nay of the whole order of Lepidoptera.

Since then the Groningen Zoological Laboratory has acquired the magnificent collection of Lepidoptera left by the lamented MAX FÜRBRINGER in Heidelberg. Thereby I was enabled to study actual specimens of mimetic butterflies in nature and this made me wish to return to the question of Mimetism in general, but then considered exclusively from a purely morphological standpoint. I desire therefore to avoid carefully the biological side of the question, though I may be allowed to express my conviction that the often