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The bigger they are, the harder they fall

by Professor E. R. Laithwaite*

The progress of Science has been called a process of "diminishing deception." Few scientists, I think, would disagree with this in principle, although they might argue that it was never their intention to deceive. Yet we must initially deceive our children, apparently, or we might confuse them entirely. What would be the use of teaching them the concepts of moving frames of reference at the age of 10, knowing that they would need this to appreciate relativistic mechanics later?

The argument, however, works both ways. There is a real danger that an enthusiastic teacher may teach the limited concepts with such fire and conviction that the pupil may well believe that he has been taught the undisputable Truth, the unbreakable Law. What is more, if that pupil should pursue an academic career in pure science, the belief in unbreakable laws may stay with him long after he has received his Nobel Prize! His influence then will be a greater hindrance to progress than the confusion of knowing at the age of 10 that there was no Truth, a confusion from which the brightest pupils would have extricated themselves, probably by the age of 16.

Let us see this fear of the unknown in action. Ohm's Law, at the time of its conception, was a neat, clean and highly useful step forward. It conformed to the idea that a flow of electricity was like the flow of water in a pipe and in this respect it gave a reality to e.m.f. that was at once helpful but undeserved. Following Faraday's discoveries in electromagnetic induction in 1831, Ohm's Law was seen as a partial truth, applicable only to the *steady* state of current. In the presence of a *changing* current, e — Ri could well be 1,000 per cent out! The modification to Ohm's Law was expressed mathematically by the next order of small differences, in the calculus notation:

$$e = Ri + L\frac{di}{dt}.$$

Now the interesting point to note is that over 140 years later no one ever says that Ohm's Law is *wrong*. It still applies to d.c. networks and, as such, is taught for O level physics. For those daring to proceed further it is simply extended, in the case of alternating current, by using the idea of a voltage wave that leads the current wave by 90° giving a net value of power over a complete cycle of events equal to zero. "Wattless current" (a term now frowned upon in the most respectable circles that favour "reactive volt-amperes") remained a mystery for many electrician apprentices in *this* century, let alone the last, because it was taught as a *fact*, rather than as a concept.

It was supposed to be helpful rather than "clever" to write a reactance as "$jL\omega$" where $j = \sqrt{-1}$. Yet everyone knows that there is literally no "real" number which, when multiplied by itself, gives "minus one." It was a cover-up for a new concept, too difficult for the average apprentice. It was recognition that magnetism was tied to electricity, which later was said to occur through a "[illegible] dimension."

The engineer, of course, was satisfied with [illegible] magic door through which one could pass from wh[illegible] been one discipline (electricity) to another (mag[illegible]). Reactive ($L\omega$ and $1/C\omega$) and complex (Z) "ohms" [illegible] as accepted as Ohm's "ohms." Although physicist[illegible] still more inclined to solve the equation

$$L\frac{d^2q}{dt^2} + R\frac{dq}{dt} + \frac{q}{c} = E \sin \omega t$$

by using the particular integral and complementar[illegible] tion than by writing the answer down at once, as a[illegible] trical engineer does. It is all a question of fami[illegible]. If you have to do it 50 times a week you will soon [illegible] an easier method than the formal solution of diffe[illegible] equations.

Now this question of familiarity raises itself a[illegible] connection with gyroscopes. The reaction of most [illegible] neers to questions on gyros is "I never did understand [illegible] properly." I'm not surprised! There is no concept [illegible] parable to inductance to relieve the mystery. Wh[illegible] worse, if there *were* such a quantity it would invo[illegible] belief in "reactive mass-acceleration" or "force [illegible] momentum change" and that (especially if the latter p[illegible] is used) casts a slur on the cherished Laws of Motion, [illegible] formulated by Isaac Newton, that "therefore cannot [illegible] wrong!" Surely we can do for Newton what Fara[illegible] did for Ohm? Let us be bold and be prepared to w[illegible]

$$\text{Force} = Mf + A\frac{df}{dt}, \text{ in place of } P = Mf.$$

An American mathematician, William O. Davis, ha[illegible] this and referred to $\frac{df}{dt}$ as "surge" (a word I myself [illegible] to the word "jerk" used by medical men to expres[illegible] of change of acceleration—yes, "medics" have studied [illegible] phenomenon ahead of the physicists and chemists). [illegible] Davis gave the quantity A the name "intractance," [illegible] fits very snugly among other words that suggest re[illegible] like "resistance," "reactance," "reluctance" and "[illegible] ance." One wonders *why* this long overdue expos[illegible] the inadequacies of Newton's Laws had to find itsel[illegible] journal such as: "Analog Science Fact and Fictio[illegible] which Davis' paper is published,† rather than in the [illegible] ceedings of a learned society, and one suspects th[illegible] author had first tried banging his head against the [illegible] of the "established church" (for I am convinced [illegible] science is a form of religion). I'm afraid that in [illegible] involving very *basic* laws, new information or even [illegible] analogy is received more as a revolution (the "blo[illegible] kind not the rotational) than as a revelation. (No co[illegible] tion with St John the Divine!)

*Imperial College, London.

† Davis, W. O. "The fourth Law of Motion." *Analog Science F[illegible] Fiction.* August 1962 (British Edition) pp. 96-107.

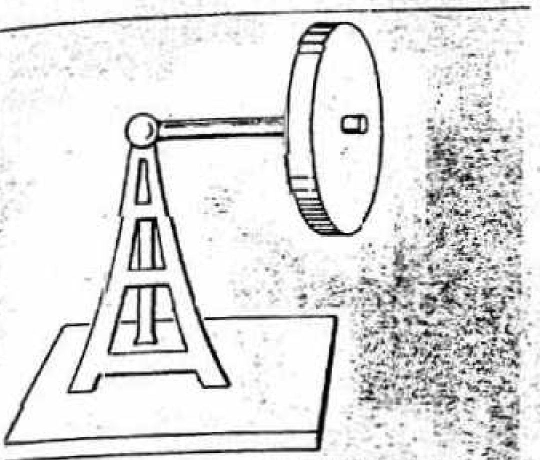

Fig. 1—*The toy gyroscope precesses on its " Eiffel Tower " without toppling*

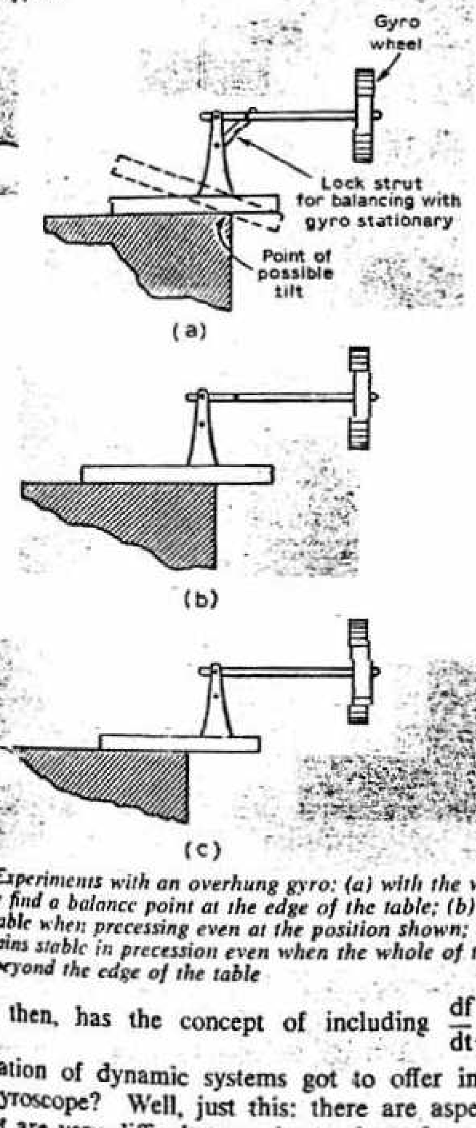

Fig. 2.—*Experiments with an overhung gyro: (a) with the wheel stationary find a balance point at the edge of the table; (b) the gyro is stable when precessing even at the position shown; (c) the gyro remains stable in precession even when the whole of the tower is beyond the edge of the table*

What then, has the concept of including $\frac{df}{dt}$ in our consideration of dynamic systems got to offer in respect of the gyroscope? Well, just this: there are aspects of a gyro that are very difficult to understand not least the fact that if you hold a bicycle wheel by its axle, get someone to give it a spin and then try to turn wheel and axle about a vertical axis, the wheel resists your efforts—but only in the axis about which you apply the twisting force. The results of your efforts are seen as the wheel axis revolves about a fore and aft axis. This motion is called precession."

Using the ordinary conservation of momentum principle the experimental behaviour is seen to conform exactly, so long as angular momentum about horizontal axes *only* is considered. But what about the fact that the wheel has a moment of inertia (I) about the vertical axis and apparently, an angular velocity about that axis Ω, and hence a momentum $I\Omega$? *Apparently*—that is the word; the momentum is only apparent, like our reactive volt-amps could be described as " apparent power." How do I know? Because I can give you a worked example of a gyro that develops *more* apparent momentum than the real momentum of the spinning wheel on its own axis. To postulate a " creation of momentum " is a far bigger heresy than postulating the need for adding a term to the Newtonian-derived equation. Yet one of the audience at a recent Royal Institution Discourse chose to say that I had claimed to create such momentum.* He can't have been attending very carefully for I would never say such a thing—you get burned at the stake for that! But what he saw and disbelieved was, I suppose, almost as provoking, for I had used an offset gyro (the kind sold in toy shops) and made bigger models so that, like induction motors, their " magic " should not escape notice.

Fig. 1 shows a typical " wheel on Eiffel Tower " arrangement, in which gravity applies the torque and the wheel precesses (gyrates) in a horizontal plane without falling from the tower. Now consider the gyro shown in Fig. 2. It differs from the toy, only in that the wheel axle is held in a stirrup at the top of the tower and the tower itself is in a bearing to allow free rotation about the vertical. First we will place the gyro on a table in the position shown in (a) where the base is on the point of tilting (as shown dotted) due to the overhung weight. The central pivot point has been locked for this purpose. Now we move it back on to the table by a very small amount (as in (b)) so that whilst it will not overbalance when static, centrifugal force in the event of rotation about the vertical will certainly pull it over. This can be demonstrated by driving the central shaft at a speed known to be great enough to topple it. The central pivot can now be unclamped and the rotor can run up to such a speed that it precesses at the same angular speed as was used in the first test, this time due to the gravitational torque. The system precesses but does *not* topple. The rotational speed, ω, required to produce a precessional speed, Ω, is given by $\omega = \frac{MgR}{I\Omega}$ where I is the moment of inertia of the rotor on its own axis.

Now we proceed to the ridiculous and pull the base out to a position such as (c) where the static pinned gyro certainly will topple in the static condition, but still it fails to topple when the gyro rotates at high speed. We must *at least* conclude that a precessing gyro displays neither angular momentum nor centrifugal force about its precession axis, and however distasteful, we have to go on to accept that we need an additional sheet anchor on which to cling, if we are to handle the " inertial equivalent " of alternating currents.

For a gyro in precession is unique in being the only object known to us that will exhibit continuous rate of change of acceleration.

Among the letters I received following the scathing attack in *New Scientist* on my proposals to update Newton, was one I particularly enjoyed, for its author referred to those who have learned to hold fast to the laws of the Establishment, as it were to a huge Rock of Ages, as the " Abominable No-Men " (they tend to shout " No " before they have done any thinking), and I'm afraid the bigger they are, the harder they fall.

Newton's laws like that of Ohm, will survive for another century and continue to be useful to those who study dynamic systems that do not rotate about two axes at the same time.

* Walgate, R., *New Scientist*, 14 November 1974, p. 470.