LXVIII. The Wiedemann effect in ferromagnetic substances

K. Honda & S. Shimizu

To cite this article: K. Honda & S. Shimizu (1903) LXVIII. The Wiedemann effect in ferromagnetic substances , Philosophical Magazine Series 6, 5:30, 650-657, DOI: [10.1080/14786440309462969](https://doi.org/10.1080/14786440309462969)

To link to this article: <http://dx.doi.org/10.1080/14786440309462969>

Published online: 15 Apr 2009.

Submit your article to this journal [↗](#)

Article views: 3

View related articles [↗](#)

Citing articles: 2 View citing articles [↗](#)

If the time of vibration of the table alone is observed and then the time of vibration of the table with a body of known moment of inertia placed on it, the moment of inertia of the table can be calculated. It is only necessary then, in determining the moment of inertia of a body about a given axis, to place it on the table in such a position that the given axis coincides with the fixed axis of vibration, and again determine the time of vibration.

Laws connecting the moments of inertia of a body about different axes can be easily verified with this table, *e. g.*, the law that "the moment of inertia of a body about any axis is equal to its moment of inertia about a parallel axis through its centre of gravity together with the moment of inertia of the whole mass collected at its centre of gravity about the given axis," can be verified by varying the distance of the body from the axis of vibration.

LXVIII. *The Wiedemann Effect in Ferromagnetic Substances.*
By K. HONDA and S. SHIMIZU*.

[Plate XVI.]

THE Wiedemann effect in iron and nickel is so well known that it is superfluous to enter into the details of the phenomenon. The experiments by G. Wiedemann†, C. G. Knott‡, Prof. H. Nagaoka and one of us§, show that so long as the longitudinal field is not strong, the direction of twist in iron coincides with that of a circular field, if this direction is right-handedly related to that of the longitudinal field; they also show that in nickel the direction of twist is opposite to that of iron in weak fields. The direction of twist is reversed when either the circular or the longitudinal field changes its direction. The Wiedemann effect in nickel steels of different percentages was recently studied by Prof. Nagaoka and one of us, and it was found that the twist is the same as that of iron. The effect of tension on the Wiedemann effect in iron and nickel was examined by C. G. Knott, who found that tension diminishes the twist in these metals.

The present paper consists of two parts; firstly, we deal with the influence of tension on the Wiedemann effect in nickel steels, and secondly, with the same effect in ferro-

* Communicated by the Authors.

† G. Wiedemann, *Pogg. Ann.* ciii. p. 571 (1858); cvi. p. 161 (1859); *Electricität*, iii. p. 797.

‡ Knott, *Trans. Roy. Soc. Edinb.* xxxii. (1), p. 193 (1882-83); xxxv. (2) p. 377 (1889); xxxvi. (2) p. 485 (1891).

§ Nagaoka and Honda, *Jour. Coll. Sci.* xiii. p. 263 (1900).

magnetic bars and the effect of torque on it. We lately published a paper* relating to the effect of tension on the magnetic change of length; in this we found that the magnetic elongation of nickel steels is largely affected by tension, and that when the tension exceeds a certain value, the contraction is accompanied by magnetization. From Maxwell's explanation as well as that of Kirchhoff for the Wiedemann effect, it seems probable that the direction of twist in nickel steels is reversed when the suspended weight exceeds the said limit. We therefore studied this point particularly and found that the above inference is not correct. So far as we were aware the Wiedemann effect in cobalt had not yet been studied, perhaps because it is difficult to obtain a specimen in the form of a wire on account of its brittleness. It was therefore desirable to have an experiment for the metal. Our apparatus† used in studying the change of rigidity by magnetization was conveniently used for examining the Wiedemann effect in ferromagnetic bars. We had two cobalt bars, one in the cast state and the other in the annealed. The observations showed that the twist in cobalt was just the reverse of that of iron, as was to be expected from its change of length by magnetization.

We tested eight different examples shown in the following table:—

Metal.	Length.	Diameter.
	cms.	cm.
45 per cent. nickel steel ...	20·80	0·0956
" " " ...	20·90	0·0516
35 per cent. nickel steel ...	20·92	0·0939
" " " ...	20·96	0·0509
Soft iron bar	21·03	1·004
Nickel bar.....	21·00	1·117
Cast cobalt bar.....	21·00	1·038
Ann. cobalt bar	21·00	1·082

Our arrangement for studying the Wiedemann effect in nickel-steel wires was the same as that used by Prof. Nagaoka and one of us in a former experiment.

To the extremities of a nickel-steel wire 21 cms. long were brazed stout brass wires, and a light mirror was attached to

* Phil. Mag. iv. p. 338 (1902).

† Ibid. iv. p. 537 (1902).

the lower brass wire. The upper wire was clamped to a small tripod which rested on the top of a magnetizing coil provided with hole- slot- and plane arrangement. One end of the accumulator was connected with the tripod while the other was led to the mercury pool placed under the suspended wire. The wire hung vertically in the axial line of the coil, which was 30 cms. long, and gave a field of 37.97 c.g.s. units at the centre by passing a current of one ampere. The vertical component of the terrestrial magnetic field was compensated by placing another coil in the interior of the magnetizing coil. The twist was measured by scale and telescope, by which a torsion of $0.2''$ per cm. was easily read.

The preliminary experiment showed that the resistance to the twist offered by the mercury in the pool was not negligibly small when the thick brass wire was dipped into the mercury. The resistance was especially noticeable when the brass wire carried a narrow rectangular piece for the purpose of damping. Hence, in order to efface the resistance, a non-magnetic nickel-steel wire 0.5 mm. thick and 5 cms. long was soldered to the lower end of the brass wire and dipped into the mercury pool. By this the damping of the torsional

oscillation was rendered very small, especially in the case when a weight was attached. To stop the oscillation a brass wire was fixed horizontally to the vertical wire and bent downward, as shown in the annexed figure. Just below it a small mercury cup was placed; this cup was connected with a large one by a caoutchouc tube. This large cup was placed near the observers and could be raised or lowered by means of a screw adjustment. The motion caused the mercury in the small cup to be raised or lowered, so that the side wire dipped into the mercury or hung free. When we wished to stop the oscillation of the wire, the side wire was dipped into the mercury in the small cup, while the reading was always taken with the wire hanging free of the mercury.

The experiment was conducted in the following manner:—

1. The circularly magnetizing current was kept constant, and the amount of twist due to varying the longitudinally magnetizing current was measured.

2. The wire was then stretched by different loads and the above processes were repeated.

3. The longitudinally magnetizing current was kept constant, and the amount of twist due to varying the circularly magnetizing current was measured.

Before each experiment care was taken to demagnetize the wire completely either longitudinally or circularly by passing an alternate current of gradually diminishing intensity. This was found absolutely necessary to secure correct results.

Twist by varying the longitudinal field.—If the direction of the longitudinal field is right-handedly related to that of the circular field, nickel steel is twisted in the direction of the latter. As shown in Pl. XVI. figs. 1 & 2, under a given circular field, the amount of twist at first increases till it reaches a maximum, after which it gradually diminishes. But the reversal of the twist is never observed, though the field exceeds 1200 c.g.s. units. The position of the maximum twist is slightly displaced in high fields as the longitudinal current increases. The amount of twist is greater in 45 per cent. nickel steel than in 35 per cent. nickel steel.

In the experiment above cited, Prof. Nagaoka and one of us observed in some cases the reversal of the direction of twist in 45 per cent. nickel steel; but in the present experiment we did not notice this reversal of twist.

The effect of tension.—The effect of tension on twist in nickel steels is not so marked as that of tension on the magnetic change of length in the same metal. As seen from figs. 3 & 4, the tension always diminishes the amount of twist; the diminution is large in weak fields, and becomes

gradually less as the field is increased. The diminution is approximately proportional to the applied tension.

To test the effect of heavy loading, thin wires about $\frac{1}{2}$ mm. thick were examined. Even by a tension at which contraction occurs by magnetization, the direction of twist in nickel steels is not reversed, though the amount of the maximum twist is reduced to about $\frac{1}{6}$ or $\frac{1}{3}$ its value corresponding to no tension, as seen from figs. 5 & 6.

Whichever theory we adopt, whether Maxwell's or Kirchhoff's, the direction of twist is principally determined by the sign of the quantity $3\lambda - \sigma$, where λ and σ are respectively the length- and the volume-change of the ferromagnetics. When there is no tension acting on the wire, the sign of $3\lambda - \sigma$ must be positive, because the direction of twist in the alloy is the same as that of iron. By applying a heavy load the magnetization is accompanied by contraction, so that λ is negative. Hence, in order that $3\lambda - \sigma$ should be positive, σ must necessarily be negative under a heavy load; that is, the change of volume by magnetization must change its sign from positive to negative as the load is increased.

Twist by varying the circular field.—In figs. 7 & 8 we notice that under a constant longitudinal field the angle of twist at first increases at a constant rate, but later at a gradually diminishing rate. As the longitudinal field is increased the curves approximate to right lines, a result which is to be expected from Kirchhoff's theory of magnetostriction. For, according to the theory, if the circular field is small compared with the longitudinal field, the amount of twist for a given longitudinal field is proportional to the longitudinal current. The amount of twist is greater in 45 per cent. nickel steel than in 35 per cent. nickel steel.

By figs. 7 & 8 we can obtain the twist under a given longitudinal current by gradually increasing the longitudinal field; the result so obtained, if it is compared with figs. 1 & 2, shows that the twist produced by the interaction of the circular and longitudinal fields is independent of the order of applying them.

The apparatus for studying the Wiedemann effect in ferromagnetic bars was that used in the experiment on the change of rigidity by magnetization; the longitudinal current was led to the bar by means of mercury contact without causing sensible resistance. The ferromagnetic bar was soldered at both ends to brass bars of thicker diameter, as in the former experiment just referred to. It was fixed by means of the

screw nut at one end of the bar in the axial line of the magnetizing coil, which was placed magnetic east and west. The pivot at the other end of the bar carrying a double wheel was lightly placed in contact with the agate cup fixed to the wooden frame. The twist was measured by means of a rotating cylinder with a reflecting mirror, a vertical scale, and a telescope. Since the Wiedemann effect is an odd function of longitudinal or circular field, it is easily distinguishable from other effects such as the change of the modulus of elasticity, which is an even function of the field. Preliminary experiments showed that the circular field has no effect upon the modulus of elasticity, perhaps because the field is not strong enough to cause such changes. They also showed that the friction at the pivot is not sensible; for the amount of twist when the pivot was left free or when it was supported gave almost coincident values. The direction of currents was also so chosen that the rotation of the mirror causes contraction of the weak spring stretching the thin copper wire. With the arrangement a twist amounting only to $1''.83 \times 10^{-3}$ per cm. of our specimen was easily read.

The measurement was conducted in the same order as in the case of nickel steels. Here we noticed that a slight residual magnetism considerably affected our results; hence, before each deflexion was taken demagnetization was carefully effected.

Twist by varying the longitudinal field.—Fig. 9 represents the curves of twist per cm. in an iron bar plotted against the external longitudinal field. Here c is the longitudinal current per square centimetre. The general course of the curves is similar to that observed in the wire of the same metal. Under a constant circular field, the angle of twist increases at first slowly and then rapidly till it reaches a maximum in a field of about 100 c.g.s. units; it then diminishes and ultimately changes its direction. The field in which the twist reaches a maximum, and also the field of reversal, are markedly larger in the bar than in the wire. Moreover, the diminution of twist in the bar, after reaching a maximum, is comparatively slow. These discrepancies will evidently disappear if we take into account the demagnetizing force acting in a direction opposite to that of the magnetizing force.

The results for nickel are drawn in fig. 10; the general features of the curves are similar to those in the wire of the same metal. The direction of twist is opposite to that of iron in weak fields; but in strong fields the direction does not

reverse. Taking into account the demagnetizing force, the discrepancies with regard to the field of the maximum twist and the slow diminution can easily be reconciled.

The direction of twist in cobalt is the same as in nickel. In cast cobalt the amount of twist is rather large, as shown in fig. 11. The twist increases at first slowly and then rapidly, till it reaches a maximum; it then gradually decreases, and ultimately changes its direction as the field is increased. Thus the course of the curves is just the reverse of that in iron. The behaviour of annealed cobalt as regards the Wiedemann effect is remarkably different from that of cast cobalt, as shown in fig. 12. In the first place the amount of twist is much smaller in the annealed than in the cast cobalt. Secondly, the field in which the twist reaches its maximum is rather large in annealed cobalt. Thirdly, the decrease of twist after reaching the maximum is very slow and its direction does not change, though the field is pushed to 1200 c.g.s. units. The results for annealed as well as for cast cobalt are just what is to be expected from the magnetostriction of these specimens. It is also to be observed that these cobalt bars were made of different samples.

Twist by varying the circular field.—Fig. 13 represents the results for soft iron; as the circular field is increased, the twist is increased first slowly and then rapidly. As the longitudinal field is increased the twist reaches a maximum and then gradually diminishes; if the field is strong enough the twist occurs at first in the opposite direction and then in the ordinary. Comparing the above result with those obtained by varying the longitudinal field, we notice one marked difference, that for the same circular and longitudinal fields the amount of twist is largely dependent on the order in which they are applied. The twist obtained by first applying the circular field and then the longitudinal is several times greater than the twist obtained when the order of applying them is reversed.

In nickel the twist is opposite to that of iron; under a given longitudinal field it increases nearly at a constant rate as the longitudinal current is increased, as seen from fig. 14. For a given longitudinal current, the twist reaches a maximum and then gradually decreases as the longitudinal field is increased. Here again we observe that the twist obtained by the application of the circular field, followed by that of the longitudinal one, is far greater than the twist obtained when the order of application is reversed.

The general feature of the twist for cobalt is similar to that in nickel. In cast cobalt (fig. 15) the twist is increased first slowly and then rapidly as the circular field is increased. With the increase of the longitudinal field the twist reaches a maximum and then gradually diminishes. If the field be strong enough the twist occurs at first in the opposite direction and then in the ordinary. In annealed cobalt (fig. 16) the twist is very small and the rate of increase is nearly constant. Here also the twist obtained by first applying the circular field and then the longitudinal is several times greater than the twist when the order of application is reversed.

The effect of torque.—To study the effect of torque, it is convenient to keep the longitudinal field constant and to vary the circular field; for, though the application of the longitudinal field is always accompanied by the twist due to the change of rigidity, the passage of a longitudinal current does not cause any appreciable twist; hence, by varying the circular field, it is not necessary to apply the correction due to the change of rigidity. The torque was given by means of the suspended weight, as in the experiment on the change of rigidity by magnetization. Keeping the longitudinal field constant, we found that in all cases the effect of torque is to diminish the twist by an amount which is nearly proportional to the torque. Figs. 17, 18, 19, & 20 show the general feature of the decrease of twist due to torque. In soft iron and annealed cobalt the effect is very small, but in nickel and cast cobalt it is considerable.

In a paper* on the mutual relation between torsion and magnetism Prof. Nagaoka and one of us have obtained from Kirchhoff's theory the result that for given longitudinal current and field, the amount of twist is inversely proportional to the square of the radius of the ferromagnetic wire. It is interesting to notice that the comparison of the above results in iron and nickel bars 1 cm. thick, obtained by varying the longitudinal field, with the corresponding results in wires of these metals about 1 mm. thick, shows the correctness of the law of the inverse square of the radius.

In conclusion, we wish to express our best thanks to Prof. Nagaoka for useful suggestions in the course of the present experiment.

* Nagaoka and Honda, Jour. Coll. Sci. xiii. p. 276; Phil. Mag. iv. p. 68 (1902).