EFFECT OF TENSION ON CHANGE OF RESISTANCE AND THERMOELECTROMOTIVE FORCE BY TRANSVERSE MAGNETIZATION

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Abstract

Effect on the resistance and thermoelectromotive force of nickel wires, of tension combined with transverse magnetization.—The wires 10 cm long and .14 cm in diameter were stretched while being magnetized transversely with a field of from 1000 to 9000 gauss. The application of tension was found to cause a marked decrease in the change due to the transverse magnetic field, both $\Delta R/R$ and $\Delta E/E\Delta t$ being decreased to half or less by a stress of 20 kg/mm^2.

Effect on the Hall and Nernst effects in a nickel plate, of tension in the direction of the electric and thermal currents was studied for a tension of 28.5kg/mm^2 and for fields up to 20,000 gauss and found to be zero. These results suggest that the Hall and Nernst effects are associated with the action of the magnetic field not on the atoms but on the free electrons, while the change of resistance and of thermoelectromotive force in a magnetic field are associated with a deformation of the atoms by the field.

Ewing's model of the ferromagnetic atom in which elliptic electronic orbits supply the magnetic control and a circular orbit the necessary Weber elements, is shown to account for the changes of length, of resistance, and of thermoelectromotive force on magnetization and the effect of tension on these changes if we assume the nickel atom is compressed in the direction of magnetization and expands at right angles, and that tension increases the stability of Weber elements with planes in the direction of the magnetic field.

IN an earlier paper the author[1] considered the influence of tension on the change of length, resistance, and thermoelectromotive force in a longitudinal magnetic field for a number of ferromagnetic substances. In nickel there was found a marked parallelism between the effects of tension on the changes of thermoelectromotive force, length, and resistance. In view of this fact it seemed of interest to study these changes in a transverse magnetic field. Because of a possible relation between the changes of resistance and the change of thermoelectromotive force on the one hand and the Hall effect and the Nernst effect on the other hand, some observations were made on the effect of tension on the Hall effect and the Nernst effect. Tomlinson[2] has pointed out that the influence of stress on

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[1] Smith, Phys. Rev. **19**, 285, 1922

[2] Tomlinson, Trans. Roy. Soc. **174**, 1–173, 1883

the Hall effect might give information concerning the nature of this effect.

METHODS OF OBSERVATION

The specimens to be studied were in the form of thin wires 10 cm long and 1.4 mm in diameter. These wires were suspended between the poles of a large electromagnet, with rectangular faces 9.5x1.8 cm, so that the magnetic field was perpendicular to the axis of the wire. For the measurement of the change of resistance suitable lead wires were soldered to the specimens so that the specimens could be connected to one side of a Kelvin double bridge by which the change of resistance was measured in the way described in a former paper.[1] The tensions were applied by placing different weights in a scale pan suspended from the wire. The observations were made at room temperature.

The change in the thermoelectromotive force was measured on a White double potentiometer. The method of observation was the same as that used in the study of the change of thermoelectromotive force in a longitudinal magnetic field. One junction was in steam at atmospheric pressure. The other was in water at room temperature. All possible precautions were taken to secure a constant difference of temperature between the junctions during a series of observations.

The Hall effect and the Nernst effect were measured by the methods employed by the author in previous studies of these effects.[3] The observations on the Hall effect were made at room temperature. The thermal flow necessary for producing the Nernst effect was obtained by keeping one end of the nickel plate on which the observations were being made at the temperature of steam at atmospheric pressure and the other end at a temperature of about 22°C. It was necessary to make provision for the application of tension to the plate. In the case of the Hall effect this tension was in the direction of the primary current. In the case of the Nernst effect the tension was applied in the direction of the thermal flow. To secure the necessary tensions, the plates were suspended between the poles of the electromagnet and weights hung from the end of a lever which was supported by one end of the plate. In this way an amplification of the applied force was obtained.

EXPERIMENTAL RESULTS

Fig. 1 shows the results obtained from the observations on the change of resistance in electrolytic nickel in a transverse magnetic field. The

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[3] Smith, Phys. Rev. **30**, 1, 1910; **32**, 193, 1911

magnetic fields have been plotted as abscissae and the fractional change of resistance as ordinates. The change of resistance in this instance is a decrease. The tensions given on the curves have been expressed in kilograms per mm². The application of tension decreases the change of resistance produced by the transverse magnetic field, a tension of 26.2 kg per mm² causing the change of resistance to decrease to less than one fourth its value for the wire without tension, whereas in the case of a longitudinal magnetic field the application of tension lessened the increase of resistance produced by smaller magnetic fields and increased the change produced by the higher magnetic fields.

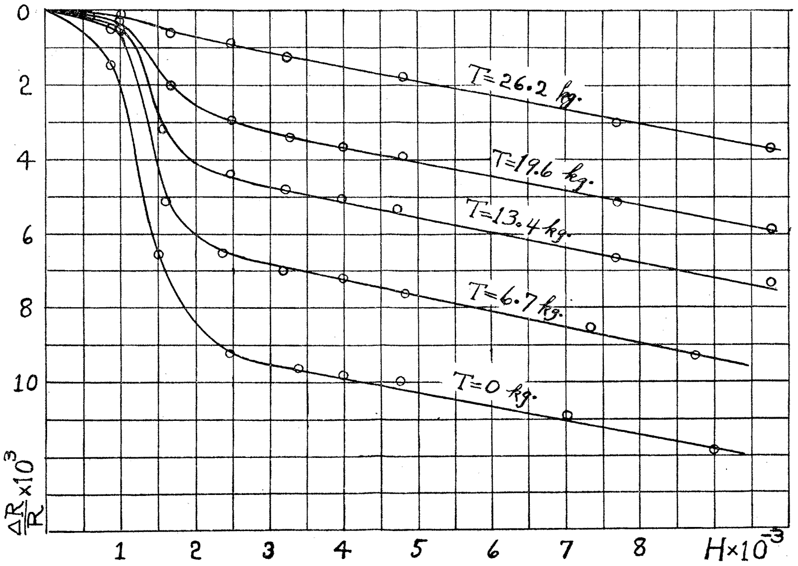

Fig. 1. The Effect of Tension on the Transverse Change of Resistance in Nickel.

In Fig. 2 the change of thermoelectromotive force in nickel against copper in a transverse magnetic field has been plotted against the magnetic field producing the change. The fractional changes in the thermoelectromotive force per degree difference in temperature between the junctions have been used as ordinates. This is the mean change for the couple when one junction is at 100°C and the other is at a temperature of about 22°C. The transverse magnetic field produces an increase in the thermoelectromitive force of the nickel against copper as shown in the figure. The application of tension operates to decrease the change of thermoelectromotive force produced by the transverse magnetic field whatever the intensity of the field, whereas in the case of a longitudinal

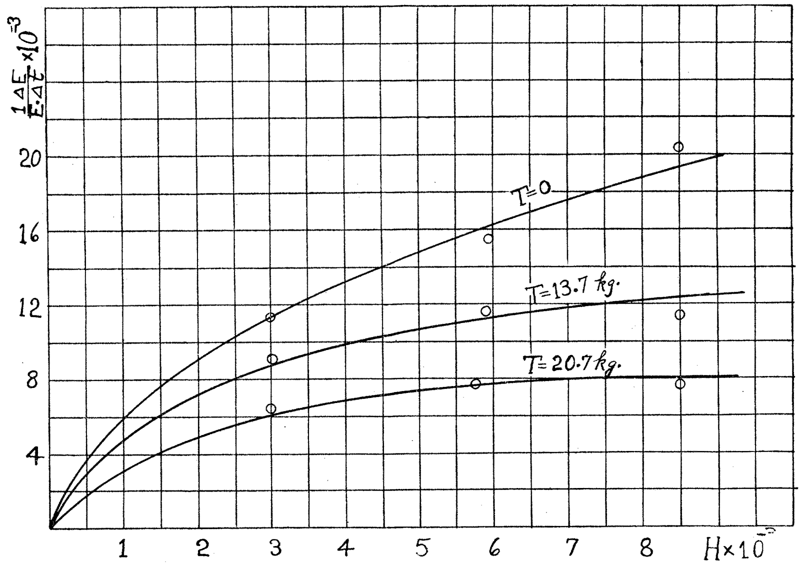

Fig. 2. The Effect of Tension on the Transverse Change of Thermoelectromotive Force in Nickel.

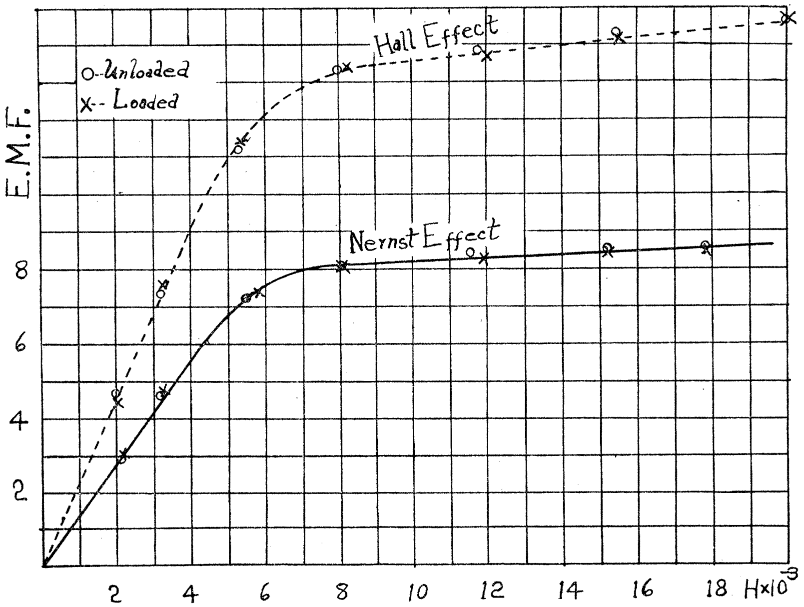

Fig. 3. The Hall Effect and the Nernst Effect in Stressed and Unstressed Nickel.

magnetic field it decreases the change of thermoelectromotive force for lower magnetic fields but increases this change for higher magnetic fields.

In Fig. 3 the dotted curve shows the Hall electromotive force in arbitrary units as a function of the magnetic field. The continuous curve shows the Nernst electromotive force as a function of the magnetic field. The circles on these curves are points obtained when the plate was unloaded. The points marked by crosses were obtained when there was a tension of 28.5 kg per mm^2 in the direction of the electric or thermal current. From these two curves it is seen that neither the Hall effect nor the Nernst effect is appreciably influenced by tension.

This negative result differs from the positive results found for the effect of tension on the change of resistance and thermoelectromotive force in a transverse magnetic field, although in each of these cases, the magnetic field is perpendicular to the direction of the tension and the tension is in the direction of the electric or thermal current. Yet tension has a marked influence on the transverse change of resistance and on the change of thermoelectromotive force but no appreciable influence on either the Hall effect or the Nernst effect.

Discussion of Results

According to Ewing's[4] recent model there is inside of a ferromagnetic atom a Weber element possessing magnetic moment and capable of being turned into allignment by sufficiently strong magnetic forces. In the case of the Bohr type of atom the necessary magnetic control is supplied by the electrodynamic action of the elliptic electronic orbits with a common focus at the nucleus of the atom. A circular electronic orbit with its center also at the common focus of the elliptic orbits supplies the necessary Weber elements. The planes of the elliptic orbits are fixed while that of the Weber element can turn. Ewing suggests that such an atom may be deformed by the application of stresses. It seems quite reasonable to suppose that it may also be deformed during the process of magnetization, on account of changes in the magnitudes of the electrodynamic forces between the Weber element and the fixed elliptic electronic orbits. It is of interest to see what this model of the ferromagnetic atom suggests as an explanation of the changes of length, resistance, and thermoelectromotive force which are observed in nickel in a longitudinal and in a transverse magnetic field.

Suppose that when the nickel atom is brought into a longitudinal magnetic field and the Weber element is oriented with its plane per-

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[4] Ewing, Phil. Mag. (6) **43**, 493, 1922

pendicular to the magnetic field, the electrodynamic action between the Weber element and the fixed electronic orbits is such as to produce a contraction of the atom in the direction of the magnetic field and an expansion in the direction perpendicular to the magnetic field. This contraction of the atom in the direction of the magnetic field would, in agreement with the observations, produce a decrease in the length of the metal. The elongation in the direction perpendicular to the magnetic field would, on the other hand, produce the elongation observed in that case. By assuming that the atoms of nickel are oblate spheroids which can be oriented by the magnetic field, Williams[5] explains in much the same way these changes in length. It seems more reasonable to suppose that the flattening of the atom is produced by the magnetic field. Besides it is doubtful as Ewing points out, whether the atom as a whole is oriented by the action of the magnetic field.

If tension in the direction of the magnetic field increases the stability of the Weber elements with planes coinciding with the direction of the magnetic field and decreases the stability of those with planes perpendicular to this direction, fewer Weber elements will be turned with their planes perpendicular to the magnetic field than would be turned by the same magnetic field in a wire without tension. Hence the contraction in the direction of the magnetic field will be less than it would be without the tension and the expansion at right angles to the magnetic field will also be decreased. Honda and Terada[6] find that the application of tension in the direction of the magnetic field decreases the change of length produced by the magnetic field until saturation is nearly reached, where the reverse takes place. There seem to be no observations on the effect of tension on the change of length in a transverse magnetic field.

Suppose that in nickel the greater part of the electric current is carried by electrons which pass from atom to atom or from atom to metal ion when conducting contact is made as a result of the incessant collisions between atoms and atoms or between atoms and ions.

Let σ = electrical conductivity of this kind; n = number of free electrons participating in the transfer of the electric current; l = the effective mean free path of electrons passing from atom to atom or from atom to ion; m = mass of electron; e = the electronic charge; v = mean velocity of electrons; T = tension applied to the wire; and H = the intensity of the magnetic field.

Then
$$\sigma=\frac{2e^2nl}{mv} \quad \text{and} \quad \left(\frac{\delta\sigma}{\delta T}\right)=\frac{2e^2n}{m}\left(\frac{\delta l}{\delta T}\right).$$

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[5] Williams, Phys. Rev. **1**, 257, 1913

[6] Honda and Terada, Phil. Mag. (6) **13**, 36, 1907

If the nickel atom is elongated by tension,

$$(\delta l/\delta T)>0 \quad \text{and} \quad (\delta\sigma/\delta T)>0.$$

This is in agreement with the observations of Tomlison[2] and Bridgman[7] who find that the application of tension increases the conductivity of nickel.

Since according to this view the atom contracts in the direction of the magnetic field, the effect of a longitudinal magnetic field on the resistance of nickel is determined by the changes in the dimensions of the atom in the direction of the electric current.

$$\left(\frac{\delta\sigma}{\delta H}\right)=\frac{2e^2n}{mv}\left(\frac{\delta l}{\delta H}\right).$$

Since when the magnetic field is in the direction of the current, $(\delta l/\delta H)<0$, it follows that $(\delta\sigma/\delta H)<0$.

If the magnetic field is perpendicular to the direction of the current, $(\delta l/\delta H)>0$ and $(\delta\sigma/\delta H)>0$. These results are in agreement with the observations that the resistance of nickel increases in a longitudinal magnetic field but decreases in a transverse magnetic field.

Under the simultaneous action of tension and the magnetic field,

$$\frac{\delta}{\delta T}\left(\frac{\delta\sigma}{\delta H}\right)=\frac{2e^2n}{mv}\frac{\delta}{\delta T}\left(\frac{\delta l}{\delta H}\right).$$

Since $(2\,e^2n/mv)$ is inherently positive,

$$\frac{\delta}{\delta T}\left(\frac{\delta\sigma}{\delta H}\right) \quad \text{and} \quad \frac{\delta}{\delta T}\left(\frac{\delta l}{\delta H}\right)$$

must always have the same sign. Now in nickel a decrease in length due to a longitudinal magnetic field is accompanied by a decrease in electrical conductivity. Hence if the application of tension decreases the change of length produced by the longitudinal magnetic field, it will also decrease the change of electrical conductivity produced by this field. This parallelism between the effect of tension on the change of resistance and the change of length in a longitudinal magnetic field has already been pointed out.

When the magnetic field is perpendicular to the direction of the current and the tension, $(\delta\sigma/\delta H)>0$ and $(\delta l/\delta H)>0$. Hence the application of tension should decrease the change of electrical conductivity produced by a transverse magnetic field, when it decreases the change of length produced by such a transverse magnetic field. The observations described in this paper show that the effect of tension is to decrease the transverse change of resistance but there seem to be no observations

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[7] Bridgman, Am. Acad. Arts and Sci. **57**, 41, 1922

on the effect of tension on the change of length in a transverse magnetic field with which to compare these results.

If the deformation of the atom produced either by the magnetic field or by tension is a function of the temperature, there will be a change in the equilibrium between the electrons and the atoms at the ends of an unequally heated wire. This change of equilibrium will manifest itself as a thermoelectromotive force which may be taken as proportional to the intensity of magnetization. Whatever, then, influences the intensity of magnetization will influence the thermoelectromotive force in much the same way and there follows the observed parallelism between the effects of tension on the change of thermoelectromotive force, change of length, and change of resistance.

The fact that tension does not influence either the Hall effect or the Nernst effect indicates that the causes which operate to produce these effects are very unlike those which cause the transverse change of thermoelectromotive force or the transverse change of resistance. If these changes of resistance, length, and thermoelectromotive force are attributed to the distortion of the atoms under tension and magnetization, the observations reported here on the Hall effect and the Nernst effect indicate that these effects are produced by the action of the magnetic field on quasi-free electrons. If such were the case it is easy to see that the magnitudes of these effects might be independent of the tension acting on the plate.

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January 29, 1923