continuous spectra are to a first approximation *not* dependent in the individual material of the electrodes and the medium, in which the discharge takes place. The intensity of all these continuous spectra increases with increasing current density, i.e., by increasing the spark energy (capacity or voltage), by confining the discharge to a smaller diameter, and by shortening the duration of the spark by reducing self-induction and Ohmic resistance or by increasing the pressure. In the spectra of the vacuum spark and of the exploded wires a continuous absorption has been found proportional to the current density. The other sparks have not yet been studied with respect to this phenomenon. All these continuous spectra are emitted only in that stage of the spark where we expect highest current and ion density. They appear always together with very broad spark lines and disappear in the later stages with decreasing broadening of the lines.

We conclude from these common properties of all the continuous spark spectra arising under such different discharge conditions that their origin must be due to the same process. There seems to be only one possibility: the radiation of free electrons in the field of the positive ions formed in the discharge, or in terms of the Bohr theory the transitions between hyperbolic orbits.

The properties which we expect from the theory for the continuous electron radiation are in best agreement with the observed properties of the continuous spark spectra. The intensity of the electron radiation is proportional to the number of collisions between electron and ions, i.e., proportional to the current density and the ion density which is determined by current density and applied voltage. The radiation is consequently to a first approximation independent of the individual properties of the ions involved. In agreement however with the experimental results we expect a small individual influence of the different ionization potentials of different elements, especially in the case of very low electron velocities due to transitions between hyperbolic and elliptic orbits. Since transitions between continuous energy levels take place in both directions, a continuous absorption must be connected with the continuous emission, in agreement with the observations on the exploded wires and the high current vacuum sparks. Since the continuous radiation is dependent on the ion density, we expect in connection with the continuous radiation the emission of spark lines, broadened by a Stark effect due to the field of the surrounding ions. Here we have also agreement between theory and observation. This agreement and the fact that there is no other possibility to explain the properties of the observed continuous spectra, seem to be a very strong argument for our explanation.

A quantitative comparison of the theoretical and experimental intensities is still impossible, because there are no exact measurements of the intensity under various excitation conditions, and the theoretical calculation is difficult because we have no exact figures for the ion density during the whole time of the spark emission. A rough calculation, however, shows that at least the order of magnitude of observed and theoretical intensity seems to be in agreement.

A detailed treatment of the problem will appear in the *Zeitschrift für Physik*.

Wolfgang Finkelnburg*
Norman Bridge Laboratory of Physics,
California Institute of Technology,
February 3, 1934.

* Fellow of the Rockefeller Foundation.

## Large Barkhausen Discontinuities and Their Propagation

While investigating the relationship between the velocity of propagation of large Barkhausen discontinuities and longitudinal field for various fixed values of tensile stress for 10 percent Ni-Fe alloy wires, it was observed that the shift of the velocity-field characteristics relative to the field axis with change in tensile stress corresponded rather accurately to the change in height of the hysteresis loop with change in tensile stress. Both of these changes were observed to saturate with tension, i.e., for high values of tensile stress a given change in tension produces a smaller shift of height of hysteresis loop or of shift of velocity-field characteristic than does the same change in tension for a lower value of tensile stress. Further, for a 70 percent Ni-Fe wire, the height of the hysteresis loop changes but little with changes in tension, and also the velocity-field characteristics shift but little with tension changes. Again, for a pure nickel wire under torsion, more qualitative indications of the dependence of the velocity of propagation upon the intensity of magnetization were observed. An increase in tension for a nickel wire under torsion caused a shift of velocity-field characteristics to higher field values while the height of the hysteresis loop was found to decrease. This is just the reverse of the case for the two alloys mentioned above for which an increase in tension was found to shift the velocity-field characteristics to lower field values and to increase the height of the hysteresis loops.

Because of such qualitative indications of the relationship between velocity and height of hysteresis loop or between $v$ and $I$ the quantitative relation existing between $v$ and $I$ was investigated. A velocity *versus* $I$ curve was obtained for a 10 percent Ni-Fe wire by holding $H$ constant and varying $I$ by means of varying the tensile stress. The $v$ *versus* $I$ curves obtained in this manner were found to be similiar in form to $v$ *versus* $H$ curves.

In a paper now in the hands of the publishers, the author has presented evidence for a 10 percent Ni-Fe alloy that in general for any strain produced by tension and torsion combined, it is only the component of field in the direction of maximum strain which influences the velocity. That is, in general, the field effecting propagation is $H\cos\theta$, where $H$ is the applied field, and $\theta$ the direction the field makes with the direction of maximum elongation. Upon considering this relation in connection with the observations relative to $I$ presented above, one might infer that the velocity might be a function of $HI\cdot\cos\theta$ only, since this satisfies the condition required above that the functional relation between $v$ and $I$ be the same as between $v$ and $H$, and also the relation between velocity and $H\cdot\cos\theta$.

The possible relationship between $v$ and $HI\cdot\cos\theta$ can be most easily tested in the case of pure tension. Here $\cos\theta=1$ and $v$ should depend upon the product $HI$ only. Table I shows the values of $H$, $I$ and $HI$ for a 10 percent

TABLE I.

| Tensile stress Kg/mm² | $H$ Oersteds | $I$ c.g.s. units | $HI$ |
|---|---|---|---|
| 25.2 | 4.80 | 1072 | 5149 |
| 28.8 | 4.51 | 1140 | 5148 |
| 32.4 | 4.27 | 1190 | 5080 |
| 37.2 | 4.03 | 1270 | 5120 |
| 42.0 | 3.84 | 1316 | 5057 |
| 46.8 | 3.68 | 1365 | 5030 |
| 51.6 | 3.55 | 1410 | 5005 |
| 57.6 | 3.40 | 1453 | 4940 |
| 63.6 | 3.30 | 1483 | 4897 |
| 72.0 | 3.27 | 1494 | 4882 |

Ni-Fe wire. The data are for a constant velocity of 6500 cm/sec. The values of $I$ were not corrected for changes in area of the wire with tension. The small change in the product $HI$ could thus easily be accounted for.

Since the velocity of propagation seems to be a function of $I$, it must be related to the magnetostrictive properties also since the relationship between $I$ and magnetostriction has been rather well established. The relationship between $v$ and the field component in the direction of maximum elongation was established for the 10 percent Ni-Fe alloy for which the magnetostriction is positive. The relationship between $v$ and the component of field in the direction of maximum strain was investigated for pure nickel for which the magnetostriction is negative. For pure nickel under torsion and tension the velocity was found to depend only upon the component of field in the direction of maximum compression. For negative magnetostriction, then, the preferred direction of orientation is along the compression axis, while for positive magnetostriction it is along the direction of maximum elongation. This leads to an understanding of why in one case the observed hysteresis loop increases with tension and in the other case decreases. In the case of positive magnetostriction the magnetic vector rotates into the direction of the wire axis with increasing tension, while in the case of negative magnetostriction it rotates away from the direction of the wire axis. Actually, the effects of tension upon the direction of preferred orientation seem to be analogous to the effects, for example, of pressure on melting point. For those alloys which tend to increase in length when being magnetized a mechanical lengthening aids the magnetizing, while for the others the reverse is true.

Investigations into the possible relationship between $v$ and $HI\cdot\cos\theta$ are contemplated in the case where wires are subjected to both tensile and torsional stresses.

RAYMOND E. REINHART

University of Kansas,
February 2, 1934.

## On the Theory of the Electron and Positive

To the paper appearing in the February 15 issue of this journal under the same title we wish to add a few further considerations. In particular the discussion of the gauge invariance of the formalism there given is incomplete, and these supplementary remarks may help to clarify the question of the proper interpretation of the theory.

(a) The solutions $\psi_{N,M}(r;\rho)$ of the wave equation (2.32) are not independent of the choice of gauge to represent the electromagnetic field. In particular the quantities

$$\sum_r\sum_\rho \bar{\psi}_{N,M}(r;\rho)\psi_{N,M}(r;\rho),$$

which give the probability of finding just $N$ electrons and $M$ positives in the system, are gauge dependent, and this gauge dependence is not directly connected with the divergence of the sums. Thus the vanishing of a $\psi_{N,M}$ can be given no physical meaning; and the vanishing of all the $\psi_{N,M}$'s except $\psi_{00}$, though a sufficient condition for the vanishing of the charge and current density everywhere, is not a necessary one. From this it follows that the number of particles in a system can be given no unambiguous physical meaning, except in those limiting cases in which one may abstract from that creation and destruction of particles which characterizes the relativistic quantum theory.

(b) The operators which represent the physical variables of the system, such as the charge and current density, the kinetic energy, the mechanical momenta $\mathbf{p}-(e/c)\mathbf{A}$, and their rate of change with time, are, formally, gauge invariant. The proof of this, which is based, in complete analogy to the proof of relativistic covariance, on the invariance of the Dirac equations and of the spurs (2.26), depends however on the assumption of the convergence of all sums.

(c) In fact the sums met with in the theory do not in general converge, and by the subtraction of the spur (2.26) their terms are automatically rearranged. Thus in practice we find that the operators representing, say, charge and current are gauge dependent; for the same reason they may depend in noncovariant manner on the choice of Lorentz frame. This point is very forcibly illustrated by considering the transformation from the constant potentials

I $\quad \mathbf{A}=0, \quad V=V_0$

to

II $\quad A_x=\sinh\beta\cdot V_0, \quad A_y=A_z=0, \quad V=\cosh\beta\cdot V_0,$

which may be regarded either as a gauge or Lorentz transformation. Whereas the expectation value of the $x$-component of the current density vanishes for the potentials I, it is infinite for II.