asymmetric broadening but it may be mentioned that it disappeared almost completely when a self-induction coil was put in series with the spark. The effect of the induction coil was to lower the potential of the spark as was quite evident from the decrease in intensity of the spark lines in comparison with the arc lines. At the same time, however, the total intensity of the spark became smaller so that the change may be due to the decrease in the density of the excited atoms.

The purchase of the fluorite vacuum spectrograph which was used in this investigation was made possible through a grant from the National Research Council to whom we wish to express our appreciation.

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May 10, 1933.

## Electromotive Forces Associated with Barkhausen Discontinuities

Recently the writer has described an experiment[1] in which an electric current was sent through a ferromagnetic wire, and discontinuities of the potential difference of the ends of the wire were observed when Barkhausen discontinuities of magnetization occurred. It was concluded that discontinuities of resistance were associated with the Barkhausen effect. More extended investigation has shown that this conclusion cannot be legitimately drawn from the experiment as described. As a matter of fact, subsequent work has demonstrated that intrinsic, impulsive e.m.f.'s are produced in the wire by the Barkhausen discontinuities, and these intrinsic e.m.f.'s are sufficiently large to mask any effect which may arise from discontinuities of resistance.

The cause of the impulsive e.m.f. associated with the Barkhausen discontinuity appears to be an inductive action which the magnetization change in one part of the wire exerts on another part. When a short straight nickel wire is laid parallel with a copper wire (insulated from the latter but very close to it), the large Barkhausen jumps in the nickel produce e.m.f.'s in the copper wire which can be detected with an amplifier and loudspeaker. If a nickel wire of large diameter is bent beyond the elastic limit into the arc of a circle and then thrust into a straight capillary tube it is in a state of elastic strain. When demagnetized by the bringing up of a bar magnet such a wire exhibits one large Barkhausen jump followed by several smaller ones. However, the impulsive e.m.f. due to the large jump, as detected at the ends of the nickel wire, is considerably weaker than the e.m.f. in a similar wire of small diameter. There appears to be a short-circuiting of the induced current by the extra material of the larger wire.

The production of an e.m.f. in a ferromagnetic wire by changes in the magnetization of the wire is not a new phenomenon. Matteucci[2] first observed it in the case of a twisted wire, where a circular component of magnetization was produced. Hippel and Stierstadt[3] have detected it in connection with the Barkhausen effect. The Matteucci effect appears to be well understood,[4] but the e.m.f. associated with the Barkhausen effect is yet to be explained adequately. Preliminary experiments suggest the following explanation.

The Barkhausen effect is known to have a transverse component,[5] that is, inductive jumps are observed in directions perpendicular to the magnetizing field. Suppose a filament in the wire, parallel to the length of the wire but of smaller diameter than the wire, to undergo a sudden change of transverse magnetization. The remaining filaments of the wire will then be subject to an induced e.m.f. parallel to their length. The situation is quite like that in which a bar magnet, held parallel to a straight wire, is suddenly turned to a transverse position, thus inducing an e.m.f. in the wire. On this view of the phenomenon we should expect parallelism between the transverse Barkhausen effect and the impulsive e.m.f.

Direct evidence that discontinuities of resistance are associated with the Barkhausen effect is lacking. The indirect evidence is as follows. Reversal of saturated magnetism in a wire does not alter its length or resistance, hence reversal of magnetism in a small element should produce no change, either of length or resistance. However, a Barkhausen jump can produce a change of length in a wire, hence we infer that this jump is not a pure reversal of magnetization in a small element. But in the latter event we expect a resistance change to accompany the Barkhausen jump, for the reason that transverse magnetoresistance is quite different in ferromagnetic materials from longitudinal magnetoresistance.

Further evidence is desirable in order to prove that Barkhausen jumps are not necessarily reversals of saturated magnetism. Possibly means may be discovered for reducing the magnitude of the induced e.m.f.'s till the resistance jumps can be detected. Another line of attack, which is being worked out in this laboratory, involves measurements of the simultaneous transverse and longitudinal components of a single large Barkhausen discontinuity in nickel.

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The Rice Institute,
May 11, 1933.

[1] C. W. Heaps, Phys. Rev. **43**, 763 (1933).
[2] Matteucci, Ann. chim. phys. **53**, 385 (1858).
[3] A. v. Hippel and O. Stierstadt, Zeits. f. Physik **69**, 52 (1931).
[4] Hans Ostermann and Fritz v. Schmoller, Zeits. f. Physik **78**, 690 (1932).
[5] Richard M. Bozorth and Joy F. Dillinger, Phys. Rev. **41**, 345 (1932).

## On the Nature of the Primary Cosmic Radiation

The latitude effects observed by Compton and Clay call for positively charged particles as responsible for some of the primary radiation. Compton[1] has emphasized the conclusion that the facts of absorption in the atmosphere

[1] A. H. Compton, *A Geographic Study of Cosmic Rays*, Phys. Rev. **43**, 357–403 (1933).

combined with the existence of directional and latitude effects necessitate the assumption that the particles originate at least several hundred kilometers above the earth's surface in order that with the energy necessary to penetrate the earth's atmosphere they can still experience sufficient bending by the earth's magnetic field to account for the facts. If the charged particles come from distances many times the earth's radius, energies comparable with $10^{10}$ volts are necessary in order that, in spite of the earth's field, they may reach the earth at latitudes as low as those at which their presence is revealed by directional and latitude effects. On the other hand, as Millikan has remarked, cloud chamber measurements have given no evidence of charged particles with energies as high as $10^{10}$ volts, and, it is difficult to suppose that absorption of energy by the atmosphere could reduce a $10^{10}$ volt-particle to an energy of $10^9$ volts, such as represents about the maximum observed in cloud chamber experiments.

Many years ago the writer[2] gave reasons founded upon the classical theory, for supposing that charged particles with sufficiently high energy may be incapable of producing ions on account of the radiationary reaction resulting from the very sharp acceleration which would be necessary were an electron to be ejected from an atom by a charged particle travelling with very nearly the velocity of light, and consequently with a field highly concentrated in its equatorial plane. Recently, he has attacked the problem on a wave mechanical basis, and has obtained an equation representing the radiation reaction terms. At his request the equation was applied to the ionization problem by Dr. Bramley[3] and it appeared that on the basis of this equation ionization should become inappreciable at about $10^{10}$ volts. If we should accept this conclusion we have a possible explanation of the difficulties cited above. We may then suppose that the primary charged particles entering the atmosphere, generate secondaries, which continue in the direction of the primaries and so carry with them the latitude effects and the directional effects fundamentally inherent in the primaries. In other words it is not the action of the magnetic field on the secondaries which is responsible for these effects, but the action of that field on the primaries. On this view the primaries would not show themselves in Geiger counters. Their properties, however, would be exemplified by the behavior of the secondaries as above implied. It is of course to be understood that the secondaries here referred to would in general serve as primaries in the sense of producing other secondaries (or tertiaries) and so on, so that there is no inconsistency in the experiments such as those of Street and Johnson[4] in which evidence is deduced in support of the view that the rays there referred to as primaries are ionizing rays. It would indeed seem that if we accept the arguments of Millikan and Compton together, they practically demand the assumption of charged particles of a non-ionizing character in line with the ideas expressed above.

A further point bearing upon the matter concerns the fact that the directional effects above referred to have indicated that the incoming primary rays are positively charged. On the view implied in this letter, however, this would not mean that the actual rays which set off the counters are positively charged. These rays might be of either sign, and the crucial experiment would be one in which it was demonstrated that these rays which inherit from the primaries a directional effect appropriate only to a positive charge may, nevertheless, themselves involve rays with charge of either sign. Cloud chamber experiments would afford information on this matter, for, quite apart from the fact that one would have to admit that secondaries will be found in the cloud chamber, one must also admit that if the primary rays exist in the number demonstrated by the directional experiments, and if they are ionizing, they certainly should show themselves in the cloud chamber and should there reveal their true energy and the sign of their charge.

On the view that the real primary rays are non-ionizing, we have yet to admit that they may be capable of causing other atomic transitions such as are associated with the emission of secondaries with high velocity, the initiation of nuclear disintegrations, etc. The relative probability of these various occurrences is a matter whose solution awaits a more complete development of the wave mechanical theory. It may be of interest to point out that if one should accept the views here tentatively suggested, one finds in them an explanation of those peculiar phenomena found by Anderson in the cloud chamber, phenomena in which a secondary appears to be ejected from a piece of lead without the evidence of any primary having entered it.

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May 11, 1933.

[2] W. F. G. Swann, *The Absence of Ionization by Electrons with Speed Comparable with that of Light*, Phil. Mag. **47**, 306–319 (1924).

[3] W. F. G. Swann and A. Bramley, *Particle Ionization for Velocities Approaching that of Light*, J. Frank. Inst. **214**, 606–608 (1932).

[4] J. C. Street and T. H. Johnson, *Concerning the Production of Secondaries by Cosmic Radiation*, Phys. Rev. **42**, 142–144 (1932).

## Erratum

### Projective Relativity and the Einstein-Mayer Unified Field Theory

(Phys. Rev. **43**, 615, 1933)

Eq. (1) on page 616 should read $g_{\lambda\theta} = \delta_{\lambda\theta}$ instead of $g_{\lambda\mu} = \delta_{\lambda\mu}$.

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