effects have been underestimated. For this reason an uncertainty amounting to 50 percent of the diffraction correction was included in computing the errors listed in Table VII, which lists the cross sections obtained from the thin absorber measurements alone.

The general result is that the nuclear cross sections for absorption plus inelastic scattering of negative pions in the energy range 85 to 137 Mev are close to the geometrical values.

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Effect of Minority Carriers on the Breakdown of Point Contact Rectifiers

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On the application of short high voltage pulses to point contact rectifiers in the inverse direction thermal instability is observed. Intrinsic conduction due to the thermal generation of electron-hole pairs and the subsequent passage of minority carriers (which are not affected by the potential barrier) is suggested as the cause of electrical breakdown.

It is well known that the standard barrier layer theory of rectification[1,2] fails to account for the phenomenon of electrical breakdown. Various mechanisms have been suggested to explain the large increase in leakage current observed when the voltage approaches a critical value. As the electrical field in the barrier layer is increased on application of a higher voltage, the following phenomena occur:

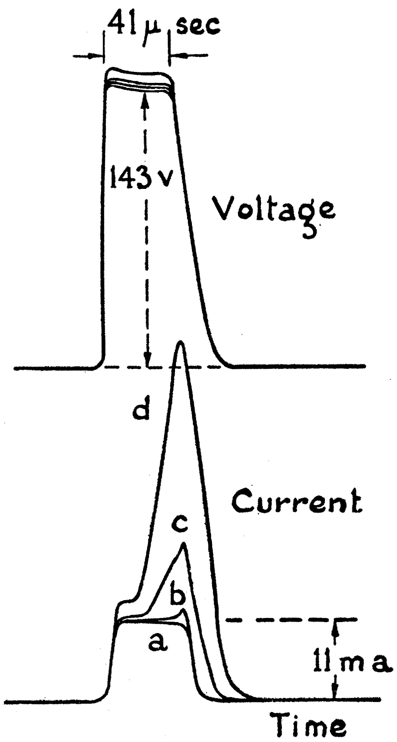

Fig. 1. Thermal instability demonstrated by the application to a Ge point contact diode of constant voltage pulses, with the pulse height increasing from curve *a* to *d*.

1. The image force[3] reduces the effective barrier height greatly easing the passage of carriers from the metal over the barrier into the semiconductor.

2. The barrier becomes sufficiently thin for carriers to tunnel[4] across it. Neither of these mechanisms by itself nor in combination is sufficient to account quantitatively for the experimental observations.

3. The power dissipated in the point contact may raise it locally to a temperature (~150°C in Ge, ~500°C in Si) sufficient for the onset of intrinsic conductivity.[5]

Thermal instability of the barrier layer has recently been shown[6] to account quantitatively for the observed breakdown values in large area (Se) rectifiers. Clear evidence for such instability in point contact rectifiers is given by the cathode-ray oscillogram traced in Fig. 1. Constant voltage pulses[7] of about 40 μsec duration,[8] produced by a low impedance generator, were applied at the rate of 300 per second to a commercial Ge point contact diode (B.T.H. Type CG1) in the inverse direction. Apart from the initial charging peak (not recorded), the current remained constant (curve a). When a certain critical voltage ($U_0 = 143$ volts) was applied, the current was observed to start rising rather suddenly towards the end of the pulse (curve b). As the voltage was raised only very slightly, the onset of the current

[1] W. Schottky, Z. Physik **118**, 539 (1942).
[2] N. F. Mott, Proc. Roy. Soc. (London) **A171**, 27 (1939).
[3] H. A. Bethe, unpublished MIT Radiation Laboratory Report No. 43-12 (1942).
[4] E. Courant, unpublished Cornell University report (1943).
[5] S. Benzer, J. Appl. Phys. **20**, 804 (1949).
[6] E. Billig, Proc. Roy. Soc. (London) **A207**, 156 (1951).
[7] This was first demonstrated by the author during a lecture on "The Physics of Transistors" given before the Institute of Physics in London on 18th March, 1952. I am indebted to Mr. M. S. Ridout for taking these oscillograms for me.
[8] Considerably shorter pulses (<1 μsec) have been used by Bennett and Hunter (Phys. Rev. **81**, 152 (1951)). The much higher voltage that contact rectifiers can withstand for such short times is in perfect agreement with the postulate of thermal instability (see reference 6).

rise occurred earlier and the current continued rising at a faster rate (curves c, d). With the voltage exceeding U_0 by only a few volts the current became excessive, being limited mainly by the external resistance. The critical voltage agreed closely with the "turn-over" value obtained on application of a continuous 50-cycle voltage.[9]

No proper explanation seems to have been given so far for the large increase in leakage current observed as the voltage is raised and the contact point reaches high temperature. In the usual rectifier model[1,2] current carriers are taken to flow from the metal into the semiconductor on application of inverse voltage; but the number of carriers available in the metal is not increased by high temperature. The explanation seems to be that by the mechanisms 1 and 2 described above—image force and tunnel effect—the current rises beyond the saturation value postulated in the simple theory. The ensuing power loss raises the local temperature at the contact point until intrinsic conduction sets in. Electrons are thus raised into the conduction band at a fast rate, leaving the same number of holes behind in the valency band. These electron-hole pairs are generated within the barrier or in its neighborhood sufficiently close by to drift towards it within their lifetime (10^{-6} to 10^{-4} second). Although the barrier is practically insuperable for the predominant carriers (electrons in n-type germanium), there is, of course, no barrier to stop the minority carriers (holes). This part of the leakage current is thus expected to rise exponentially with temperature and to become dominant as the intrinsic temperature is approached. The possibility of electrons and holes simultaneously carrying the current has already been discussed,[10] but the origin of the minority carriers, namely, intrinsic generation, seems to have escaped explanation so far.

[9] The current pulse as displayed on the cathode-ray screen remained steady for curves a and b. When the mean power exceeded about 25 mw, the current pulse crept up visibly. The power loss then apparently exceeded the heat dissipation, with the rectifier temperature increasing from one pulse to the next.

[10] J. Bardeen and W. H. Brattain, Phys. Rev. **75**, 1208 (1949).

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Equivalence Theorems for Pseudoscalar Coupling*

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By a unitary transformation a rigorous equivalence theorem is established for the pseudoscalar coupling of pseudoscalar mesons (neutral and charged) to a second-quantized nucleon field. By the transformation the linear pseudoscalar coupling is eliminated in favor of a nonlinear pseudovector coupling term together with other terms. Among these is a term corresponding to a variation of the effective rest mass of the nucleons with position through its dependence on the meson potentials. The question of the connection of the nonlinear pseudovector coupling with heuristic proposals that such a coupling may account for the saturation of nuclear forces and the independence of single nucleon motions in nuclei is briefly discussed. The new representation of the Hamiltonian may have particular value in constructing a strong coupling theory of pseudoscalar coupled meson fields. Some theorems on a class of unitary transformations of which the present transformation is an example are stated and proved in an appendix.

INTRODUCTION

In a recent communication[1] by one of the present authors it was demonstrated that by performing a particular unitary transformation on the Hamiltonian describing the interaction of a nucleon with a neutral pseudoscalar meson field through pseudoscalar coupling a new representation of the Hamiltonian was obtained which gave prominence to some features of this theory which are obscured in the usual representation. The present paper is the first of a series whose purpose is to generalize these results and to investigate, and perhaps exploit, their significance in our understanding of nucleonic properties and nuclear forces.

The unitary transformation referred to above can be regarded as generating a rigorous equivalence theorem, correct to all orders in the coupling constant, connecting the simple pseudoscalar coupling in the original representation with pseudovector coupling in the new representation. The latter is particularly interesting because the pseudovector coupling term has a nonlinear character of a type which one would anticipate would lead to saturating of the nucleon-meson coupling in the presence of large meson potentials. The attractive possibility is therefore suggested that within the framework of the ordinary pseudoscalar meson theory with simple pseudoscalar coupling may lie just the elements of nonlinear behavior responsible for the saturation of nuclear forces and for the relative independence of one-particle motions in nuclei (as evidenced by nuclear shell structure) which have been proposed on a heuristic

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[1] L. L. Foldy, Phys. Rev. **84**, 168 (1951).