Studies on a 3-Terminal Hall Effect Device

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(Z. Naturforschg. 19 a, 1629—1630 [1964]; eingegangen am 18. Juni 1964)

Normal HALL generators are provided with four terminals, two carrying the current and two serving as the so-called HALL electrodes across which the HALL voltage is developed. If these latter terminals are connected together externally through a suitable resistance they can jointly be used to serve as a current lead and thus replace one of the current terminals of a normal HALL generator. The device under such condition is essentially a three-terminal one, the terminals forming the vertices of a triangle. It is the purpose of the present note to report the results of some investigations undertaken on such a device.

Experimental Arrangement and Results

A thin rectangular bar of n-type InAs having the dimensions $12 \times 6 \times .1$ mm was chosen. Three small area contacts (1, 3 and 4) as shown in Fig. 1 were made on the sample, care being taken that there was no appreciable contact resistance. Electrical connections were then

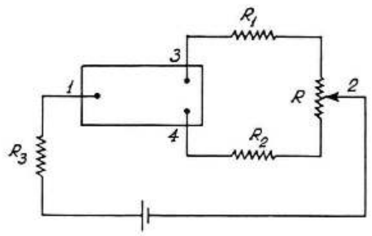

Fig. 1. Schematic diagram of the 3-terminal device.

made as shown in the same figure. Terminals 3 and 4 were properly aligned by adjusting the terminating shunt resistance R so that no voltage was present between them, in the absence of a magnetic field. The device was placed between the pole pieces of an electromagnet and the voltage drops across terminals $1-3$, $1-4$ and $3-4$ (designated as V_{13}, V_{14} and V_{34} respectively) were measured for various values of the magnetic field. Measurements were also made by reversing the directions of both current and magnetic field. Results thus obtained are plotted in Figs. 2 and 3 (crosses and hollow circles). The following main features are observed:

(i) With the magnetic field in a particular direction (let us call this direct), the voltage V_{13} is found to increase steadily with B while V_{14} first decreases, passes through a minimum and then begins to rise (Fig. 2, crosses).

(ii) On reversing the magnetic field, the types of variation of the voltages V_{13} and V_{14} are interchanged (Fig. 2, hollow circles). In both cases, reversal of current direction did not produce any change in the results.

(iii) The voltage V_{34} increases almost linearly with B (Fig. 3) having a slope equal to 50.0×10^{-8} for both directions of the magnetic field.

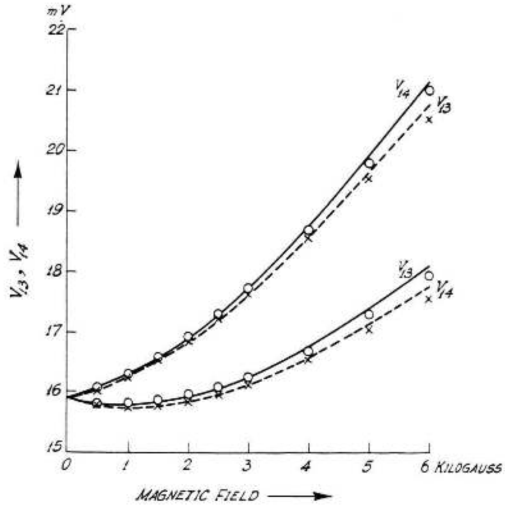

Fig. 2. Showing the variation of V_{13} and V_{14} with magnetic field (broken line for direct and continuous line for reverse field). Crosses and hollow circles show experimental points for direct and reverse magnetic fields respectively.

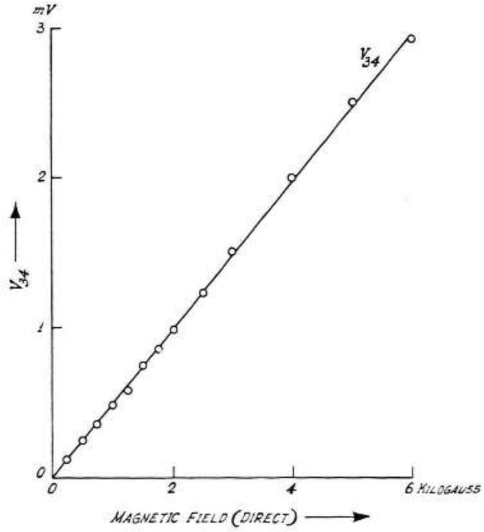

Fig. 3. Showing the variation of V_{34} with magnetic field.

Theory of Operation of the Device

The observed characteristics of the device may be explained by considering both the magnetoresistance and HALL effect phenomena in the specimen.

In the absence of any magnetic field, the voltage drops across terminals $1-3$ and $1-4$ represent the ohmic drops across these terminals. When a magnetic field is applied normal to the direction of current flow, the voltage across both terminals $1-3$ and $1-4$ would be affected due to two factors. One of these factors is the well known magnetoresistance effect. Assuming that the magnetoresistance effect of the specimen can be expressed [1] by the relation

$$\Delta\varrho/\varrho_0 = C\,B^x \tag{1}$$

where $\Delta\varrho$ = change in resistivity due to application of a magnetic field B, ϱ_0 = resistivity in absence of any magnetic field, and C and x constants for the material of the specimen under investigation, it follows that the voltage drop across terminals $1-3$ and $1-4$ would each increase by an amount $V_0\,C\,B^x$ where V_0 is the voltage drop in zero magnetic field.

The other factor responsible for the change of V_{13} and V_{14} is the HALL effect. While an exact expression for the magnitude of this change can not be readily given, one may as a first approximation assume this to be proportional to B and also to the current in the other branch. Further, if V_{13} rises due to this effect, V_{14} would fall and vice versa. Thus the expressions for V_{13} and V_{14} as function of magnetic field B may be written as

$$V_{13} = V_0 + b\,i_{14}\,B + V_0\,C\,B^x, \tag{2}$$

$$V_{14} = V_0 - b\,i_{13}\,B + V_0\,C\,B^x \tag{3}$$

where i_{13} and i_{14} are currents in the branches $1-3$ and $1-4$ respectively and b is a constant of proportionality. The nature of Eq. (3) suggests that V_{14} would pass through a minimum as B is increased (since x is usually greater than 1). To obtain the position of the minimum, differentiating Eq. (3) and equating to zero give

$$B_{\min} = \left(\frac{i_{13}\,b}{x\,V_0\,C}\right)^{1/(x-1)}. \tag{4}$$

As B is increased beyond $B_{\min}$, V_{14} begins to rise and would attain the value V_0 at some value of the magnetic field B. Designating the latter by B_0, say, we have

$$B_0 = \left[\frac{i_{13}\,b}{V_0\,C}\right]^{1/(x-1)}. \tag{5}$$

To obtain an expression for V_{34} we note from Eqs. (2) and (3), that

$$V_{34} = V_{13} - V_{14} = (i_{13} + i_{14})\;b\,B\,. \tag{6}$$

Eq. (6) enables us to find out the constant b from the slope of the V_{34} versus B, provided the total current through the sample is known.

Again, by utilising Eqs. (4) and (5) one obtains

$$x = [B_0/B_{\min}]^{x-1} \quad \text{or,} \quad x^{1/(x-1)} = [B_0/B_{\min}]\,. \tag{7}$$

Hence x can be calculated. Further, putting the value of x into Eqs. (4) or (5), C can be obtained.

Testing the Validity of the Theory

In order to check the validity of the theory outlined above, the experimental results reported were compared with those predicted by the theory.

Let us begin the discussion with Eq. (6) which shows that the plot of V_{34} versus B should be a straight line. As shown in Fig. 3 this characteristic is indeed almost linear. Again, from the slope of this characteristic, since the total current through the sample is known (10 mA) one can determine b which comes out to be 5.0×10^{-5} cm^2/coulomb. Now, the HALL coefficient R_H of the sample was found from HALL effect measurements to be 66 cm^3/coulomb. Dividing this by the thickness t of the sample one obtains a value of 6.6×10^{-5} for $R_H/t\times10^{-8}$ which is in fair agreement with the value of b as reported above. This confirms the assumption made in the preceding section, viz., that the voltage V_{34} is due to the well known HALL effect.

Now, as mentioned in connection with Eq. (7) both x and C can be determined by measuring the values of B_0 and $B_{\min}$. The values of x and C thus obtained are 1.8 and 3.62×10^{-8} (Gauss)$^{-1.8}$ respectively. Utilizing these values of C and x and knowing the values of V_0, b, i_{13} and i_{14} the voltages V_{13} and V_{14} were calculated theoretically for different values of B, using Eqs. (2) and (3), and are plotted in Fig. 2. It is seen that the theoretical values are in satisfactory agreement with the experimental results. This proves the validity of Eqs. (2) and (3).

Concluding Remarks

The three terminal device can be used in almost all applications where the conventional four terminal HALL generators are used. Other applications of the device could also be found utilizing the simultaneous application of the HALL and magnetoresistance effects, as, for example, the development of an analogue function generator [2]. Investigations along this line are in progress.

Acknowledgements

Thanks are due to Prof. J. N. BHAR for his kind interest in the work.

[1] H. WEISS, Z. Naturforschg. **12 a**, 80 [1957].

[2] S. KATAOKA and H. YAMADA, Proc. I. R. E. **50**, 2522 [1962].