Production of Induced Radioactivity by the Cosmic Radiation

Examination of the "bursts" or "Stösse" obtained on a Compton-Bennett world-survey type of cosmic-ray meter converted to continuous recording at the Huancayo Magnetic Observatory, Peru (altitude 3300 meters, geomagnetic latitude, 0°) gives the surprising information that a number of the bursts are double—and in one case, doubtfully triple. The records were obtained on a relatively open time scale, 138 mm per hour or 2.3 mm per minute, and at the low sensitivity of 1.5×10^7 ions per mm. In all, with one brass and one lead shield, each 2.5 cm thick, 14 double bursts occurred with time-separation between the two bursts of less than one minute, the total number of bursts recorded with this screening arrangement being 927 obtained during 1344 hours of recording. This is 94 times the number to be expected on statistical grounds. Out of the 634 obtained during 1524 hours recording with an additional lead shield of 2.5-cm thickness, 5 were double with time-separation of less than one minute, or 164 times the number expected statistically. The time-intervals between the two bursts constituting a double varied between 23 and 55 sec. ± 3 sec. We are therefore led to believe that the lead is responsible for the production of these particular doubles, for the ratio, actual to expected, was raised by the additional lead, although the actual number was reduced.

It seems that we are here dealing with an example of induced radioactivity. The time-differences between the original and second bursts of the doubles is not constant but the differences tend to group around one or two values, 26 seconds and 44 seconds. The number of bursts is too small to be able to draw any very definite conclusion about the distribution in time after the original burst and so state that the disintegrations follow the laws of radioactive decay, especially when the differences tend to group around two values. The pertinent data regarding the doubles and the one doubtful triple are given in Table I.

TABLE I. *Data concerning double bursts and one doubtful triple burst.*

Ions produced ($\times 10^6$)			Time-interval (sec.)		Ions produced ($\times 10^6$)			Time-interval (sec.)	
1st	2nd	3rd	1st to 2nd	to 3rd	1st	2nd	3rd	1st to 2nd	to 3rd
Shields: brass and lead, 2.5 cm each									
3.0	3.0		55 ± 3		1.6	8.2		23 ± 3	
12.3	12.3		47 "		1.6	14.2	6.3	52 "	36 ± 3
2.3	3.5		52 "		5.0	6.7		29 "	
6.3	4.7		29 "		10.2	1.7		44 "	
3.2	4.8		26 "		3.4	1.7		44 "	
1.6	13.0		34 "		13.8	3.4		47 "	
3.3	4.9		44 "						
Shields: brass, lead and lead, 2.5 cm each									
1.4	2.7		50 ± 3		1.8	3.5		39 ± 3	
9.1	19.6		50 "		3.5	5.3		23 "	
3.5	3.5		26 "						

In these experiments the sensitivity was low so that no single alpha-particle effect could have been detected, and the circuit was so arranged that no rate of change of potential effects could affect the measurements. The average number of ions produced during the double bursts was 5.3×10^6 in the first burst and 5.6×10^6 in the second, ranging from 1.5 to 19.6×10^6 as may be seen from the table. Further results will be published shortly.

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Theory of the Piezo-Resistive Effect

It is herein meant by the piezo-resistive effect that change in electrical resistance which a homogeneous body undergoes when subjected to mechanical stress. From the experiments of Mildred Allen on bismuth[1] one is led to assume that in the most general case the changes of resistance are a linear function of the components of the applied stress. In tensor notation the law of the piezo-resistive effect is, therefore:

$$\Delta r_i = R_i - r_i = \sum_{j=1}^{6} \rho_{ij} X_j; \quad i = 1, 2 \cdots 6, \tag{1}$$

wherein Δr_i is the resistance change, r_i is the resistance in the direction i in the unstressed state, R_i is the resistance in the stressed state, ρ_{ij} are to be the piezo-resistive constants, X_j are the stress components of Love in the notation of Goranson,[2] and the axes of reference are the crystallographic.

The reduction of the constants must be by the so-called geometric method utilizing Neuman's hypothesis, so that for certain rotations or reflections depending upon the symmetry of the crystal, (1) takes the following form in the new (primed) system:[3]

$$r_i' = R_i' - r_i' = \sum_{j=1}^{6} \rho_{ij} X_j', \tag{2}$$

where it may be shown that the R_i''s transform exactly as do the stress components given by Love,[4] and because of their higher symmetry

$$r_i' = r_i; \quad r_i = 0 \text{ if } i = 4, 5 \text{ or } 6. \tag{3}$$

Let the theory be illustrated for the bismuth crystal in which according to Bridgman[5] the X axis is the digonal and the trigonal axis is Z. Thus the transformations for the X_j''s as well as for the R_i''s for the rotation about X and Z are respectively:

$$\begin{aligned} X_1' &= X_1; & X_2' &= X_2; & X_3' &= X_3; \\ X_4' &= X_4; & X_5' &= -X_5; & X_6' &= -X_6. \end{aligned} \tag{4a}$$

$$\begin{aligned} X_1' &= \tfrac{1}{4}X_1 + \tfrac{3}{4}X_2 - \tfrac{1}{2}\sqrt{3}\, X_6; & X_2' &= \tfrac{3}{4}X_1 + \tfrac{1}{4}X_2 + \tfrac{1}{2}\sqrt{3}\, X_6; \\ X_3' &= X_3; & X_4' &= -\tfrac{1}{2}X_4 - \tfrac{1}{2}\sqrt{3}\, X_5; \\ X_5' &= \tfrac{1}{2}\sqrt{3}\, X_4 - \tfrac{1}{2}X_5; & X_6' &= \tfrac{1}{4}\sqrt{3}\, (X_1 - X_2) - \tfrac{1}{2}X_6. \end{aligned} \tag{4b}$$

Substitution of (4a) and (3) in (2) and comparison with (1) show that on account of the digonal symmetry of the X axis that

$$\rho_{15}=\rho_{16}=\rho_{25}=\rho_{26}=\rho_{35}=\rho_{36}=\rho_{45}=\rho_{46}=\rho_{51}=\rho_{52}=\rho_{53}=\rho_{54}=\rho_{61}=\rho_{62}=\rho_{63}=\rho_{64}=0. \quad (5)$$

The rotation about the Z axis together with (5) demands that the relations expressed in the following matrix of 8 separate constants exist:

$$\begin{matrix} \rho_{11} & \rho_{12} & \rho_{13} & \rho_{14} & 0 & 0 \\ \rho_{12} & \rho_{11} & \rho_{13} & -\rho_{14} & 0 & 0 \\ \rho_{31} & \rho_{31} & \rho_{33} & 0 & 0 & 0 \\ \rho_{41} & -\rho_{41} & 0 & \rho_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & \rho_{44} & 2\rho_{41} \\ 0 & 0 & 0 & 0 & \rho_{14} & (\rho_{11}-\rho_{12}). \end{matrix} \quad (6)$$

Eight, then is the minimum number of constants to completely express the piezo-resistive effect in bismuth. Notice that $\rho_{ij}\neq\rho_{ji}$ when $i\pm j$. Therefore in the general or triclinic case 36 constants are needed. The reduction of the constants for any crystal class is to be noted as being exactly the same as that for the piezo-optical effect and the changes of the coefficients of thermal conductivity of a body under stress which have been studied by Pockels, the matrices for which may be found elsewhere.[6, 7]

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[4] Reference 3, p. 78.
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