Concerning the Anomalous Scattering of Mesotrons

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MAKING use of a method developed by the writer[1] Sinha[2] has recently calculated the cross section for the anomalous scattering of mesotrons within a band of low energies. In this method the energies of the individual scattered particles are not determined but the distributions in angle of the particles scattered in two lead plates of different thicknesses are compared.

As Sinha has pointed out, the writer's earlier calculation of the number of singly, or anomalously, scattered particles was not strictly accurate since in this calculation an approximation was required because of the fact that when expressed as a function of $u=\theta t^{-\frac{1}{2}}$ the distributions observed with two thicknesses of lead had different upper and lower limits. When this calculation was published it was assumed that the error thus introduced was small compared with the statistical errors of the observations. A more rigorous analysis of the problem recently undertaken in connection with the reduction of a much larger mass of experimental data has revealed that even in these preliminary results the estimates of the anomalous scattering were significantly affected by errors introduced in the approximations and the calculated cross sections for the anomalous scattering were consequently too small. The improved method of analysis will be published soon along with a report on the analysis of additional experimental data.

There remain several discrepancies between the procedures employed by Sinha and by the writer. The values for $f(u)$ given in Table II of Sinha's article should be multiplied by a factor of $\frac{1}{2}$. This leads to a value for the quantity δ of 30.2 percent. Furthermore, it has not been taken into account that δ represents the difference between two *integrals* of $f(u)$ over the same range of u but over different ranges of scattered angles. Therefore the writer believes that Sinha's method of obtaining the quantity K from δ is incorrect. Using Sinha's data the writer has re-calculated a scattering cross section, and, because of cancellation of the several errors mentioned, accidental agreement is found for this and Sinha's original values except for the amount of the standard error which turns out to be almost twice as large as that given by Sinha.

The new results following from Sinha's and the writer's experiments are given in Table I. Results obtained from an earlier article by Code[3] have also been included for comparison. Lower and upper limits for the observed ranges of the scattering deflections and energies of the particles are indicated in columns 3 and 4. Next, the cross sections for the anomalous scattering are listed. These cross sections represent averages over the ranges given and refer to one neutron or proton in lead or tungsten. It is seen that satisfactory agreement exists for Code's and the writer's last values for the scattering cross sections, the only two values belonging to nearly equal ranges for deflections and energies which may be compared directly.

TABLE I. Cross sections for anomalous scattering.

1	2	3	4	5	6
Author	Method	Limits of range of deflections involved Degrees	Limits of range of energies involved 10^8 ev	Average cross section 10^{-28} cm² per nucleon	Fraction of total, scattered anomalously %
Sinha	2 lead plates, 2 and 4 cm thick, resp.	4 ÷24	0.55 ÷1.55	170±75	65±30
Code	1 tungsten plate, 3.8 cm thick, energy measured by magn. field	9 ÷90	6 ÷ ∞	6±2	80±20
Shutt	2 lead plates, 1 and 5 cm thick, resp.	4.5 ÷27	0.2 ÷ ∞	16±2	55±10
		4.5 ÷27	4.5 ÷ ∞	20±3	88±12
		9 ÷27	0.2 ÷ ∞	3±1	35±19
		9 ÷27	4.5 ÷ ∞	5±2	81±19

Sinha's value is (10±5) times as large as the writer's first value for a similar range of scattering angles. As Sinha concludes, the reason for this discrepancy may lie in the difference of the energy ranges within which the observations were made.

In the sixth column the fraction of the total number of deflected particles is given for the number of mesotrons that are scattered anomalously. It appears that approximately 50 percent of the mesotrons are scattered anomalously if low energies are included while for energies greater than $\sim 5\times 10^8$ ev the scattering seems to be almost exclusively anomalous.

[1] R. P. Shutt, Phys. Rev. **61**, 6 (1942).
[2] M. S. Sinha, Phys. Rev. **68**, 153 (1945).
[3] F. L. Code, Phys. Rev. **59**, 229 (1941).

A Theoretical Criterion for the Initiation of Slip Bands

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AS was first recognized at the end of the last century,[1] initial plastic deformation occurs in most metals through the propagation of slip bands. It is therefore reasonable to expect that in these metals the over-all stress necessary to initiate plastic deformation may be computed by the condition that such stress be sufficient to propagate slip bands. The purpose of this letter is to present the computation for the yield stress of metals according to this viewpoint, and to demonstrate that the results appear to be in agreement with observations.

From observations upon the mechanical behavior at low stress levels of freshly deformed metals,[2] it appears that the material within a freshly formed slip band behaves in a viscous manner,[3] and that the rate at which shear stress is relieved decreases rapidly with the time since its formation.[4] It is therefore reasonable to assume that during

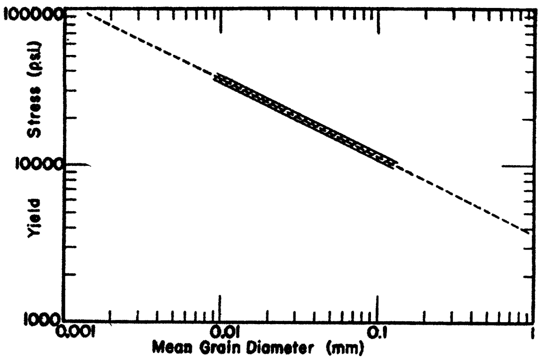

FIG. 1. Comparison of Eq. (1) with data on silicon brass in reference 7. Cross-hatched region observed "apparent elastic limit." Dotted line, Eq. (1) with $C=1.8$.

its propagation, which is too rapid to follow visually, all shear stress is relieved across a slip band. Such relief of shear stress within a slip band necessarily results in a large concentration of shear stress just ahead of its advancing edge, hereafter called its spearhead. The condition that a slip band propagate is that this stress concentration be sufficient to induce plastic deformation in front of the spearhead.

Under the above assumptions the stress concentration factor is given by[5] stress concentration factor $\simeq(L/\rho)^{\frac{1}{2}}$, where L is the lateral diameter of the slip band and ρ is the radius of curvature of the spearhead. The local shear stress necessary to induce plastic deformation in a previously undisturbed lattice is given by[6]

$$\text{local shear stress}\simeq G,$$

where G is the shear modulus. The macroshear stress necessary for slip band propagation is therefore

$$\text{macro shear stress}\simeq(\rho/L)^{\frac{1}{2}}G.$$

The advancing spearhead will probably be as thin as is consistent with the atomic structure of the metal. ρ will therefore be replaced by the spacing d of the atomic planes parallel to the slip band. On the other hand, slip bands are confined to individual grains, and therefore L is less than a grain diameter. The yield stress, which is effectively the least tensile stress which induces plastic deformation, is, according to the above viewpoint, therefore given by

$$\text{yield stress}=C(d/D)^{\frac{1}{2}}\cdot G, \qquad (1)$$

where D is any convenient measure of the average grain diameter, e.g., the standard "grain size," and C is a numerical coefficient of the order of magnitude of unity. A comparison of Eq. (1) with the extensive data[7] on copper alloys indicates the essential correctness of the above approach. Figure 1 is presented as an example of the type of agreement obtained.

According to the above viewpoint, a slip band must already have attained a critical length before it can propagate under a given macro stress. The same type of difficulty is encountered in a description of a change of phase—a particle of a new phase can grow only after it has already attained a critical size. The nucleus of a slip band presumably forms, as does the nucleus of a new phase, by some sort of thermal fluctuation, perhaps of dislocations. The comparatively slight effect of changes in temperature and in strain rate upon the observed yield stress probably enters through their effect upon the rate of formation of new nuclei.

Resistance to deformation by twinning is of the same order of magnitude as is the resistance to deformation by slip bands. The spearhead of a twin and of a slip band must therefore propagate in essentially the same manner. Depending upon the plane of the spearhead, the material further back deforms either in an orderly manner, thereby resulting in a twin band, or in a disorderly manner, thereby resulting in a slip band.

Except in metals containing obvious gross cavities, such as cast iron, and in metals of complex structure, fracture is always preceded by at least a slight plastic deformation. It appears that the stress concentration at the end of a slip band, stopped either by a grain boundary or by a precipitate, forms a small micro-crack of sufficient size that the conditions of Griffith[8] allow its further propagation. Equation (1) therefore gives a lower limit for the fracture stress.

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[2] J. Muir, Phil. Trans. Roy. Soc. **193**, 1 (1900).
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The Low Energy β-Spectrum of Cu^{64}

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THE measurements of Backus[1] on the low energy end of the β-spectra of Cu^{64}, which branches to Zn and Ni, show a type of discrimination between electron and positron emission that is not contained in the Fermi theory. Between 5 kev and 50 kev the electron intensity is very closely proportional to the kinetic energy of the emitted electron, while the theory predicts a sensibly constant intensity over this range (within a few percent). However, the positron spectrum is in excellent agreement with the theory, so that it is unlikely that the electron behavior is caused by an idiosyncrasy of the apparatus. Also, the measurements of Tyler[2] on Cu^{64} contain this discrimination, though, in Tyler's case, it is masked by scattering from the source and support.

That this constitutes a crucial test of the theory may be seen from the fact that the five relativistically invariant interaction hypotheses available in a theory of the Fermi type each predict the constant electron behavior. However, there are two linear combinations, the difference between the scalar and vector interactions, and the difference between the tensor and pseudovector interactions, which will fit the observed electron spectrum, and not impair the agreement with the positron spectrum.[3] These interactions essentially multiply the Fermi distribution by $1-mc^2/E$ for electrons, and by $1+mc^2/E$ in the case of positron emission, where E is the energy of the emitted β-ray, including