It remains to show why dislocations should have portions lying in particular glide planes and pass out of these glide planes at particular points. This is to be expected if dislocation lines have lower energy in particular crystallographic planes. A theory of the reduction in energy can be given for the particular cases of the close packed planes in h.c.p. and f.c.c. metals in terms of dissociation into "extended dislocations."[4] These metals are the ones for which slip on particular planes is most characteristic.

It is necessary for the mechanism we have described that the end points B and C should be anchored at least in some degree. This anchoring may be provided in various ways in dislocation networks, the simplest example being that in which BC is one side of a rectangular dislocation loop $ABCD$, the Burgers vector being normal to the plane of the loop. The stress which causes the motion of BC in Fig. 3 produces an opposite motion of AD, with no net force on AB and CD. In many cases (e.g., probably the hexagonal metals) the lower mobility of dislocations in planes of less than closest packing may suffice to anchor the points B and C.

[1] F. C. Frank, Report of a Conference on the Strength of Solids (Physical Society, London, 1948), p. 46.
[2] G. Liebfried, Zeits. f. Physik **127**, 344 (1950).
[3] F. C. Frank, Discussions of the Faraday Society **5**, 67 (1949).
[4] R. D. Heidenreich and W. Shockley, Report of a Conference on the Strength of Solids (Physical Society, London, 1946), p. 71.

Prismatic Dislocations and Prismatic Punching in Crystals

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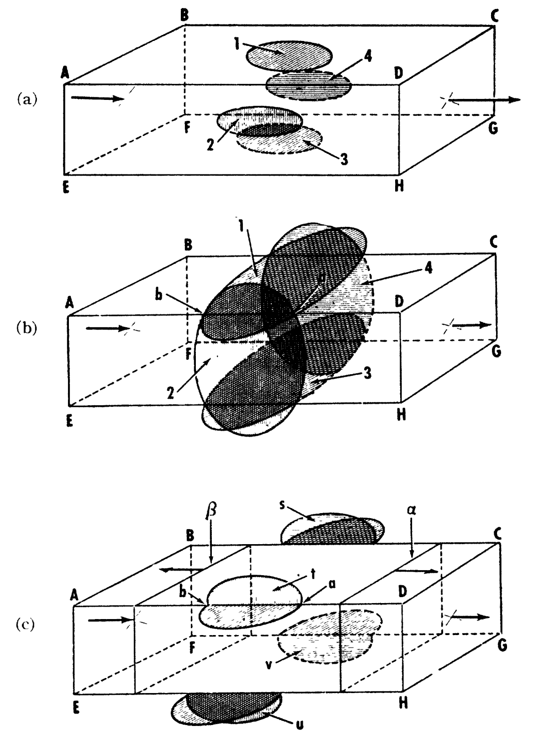

FIG. 1. Possible forms of dislocation rings.

SMAKULA and Klein[1] have made indentation studies of the plastic properties of the thallous halides with use of a small conical punch and have found that the strain may be transmitted in a highly concentrated manner through distances large compared to the dimensions of the hole made by the punch. The system behaves as if the punch pushed cylinders or prisms of the material as rigid units in the direction of the axis of the prism, the length of the prism being relatively large compared with the sectional dimensions. The prisms appear to be polygonal in cross section, the planar surfaces being slip planes (110) and the direction of the axis being slip directions (100). A single prism having square cross section is pushed if the indenter is pressed in the (100) direction, but two and three are pushed, respectively, if the load is applied in the (110) and (111) directions. In the latter two cases the axes of the prisms lie in different, symmetrically equivalent, (100) directions. We shall term this *prismatic punching*.

In order to explain these rather dramatic results it is only necessary to discover a mechanism whereby dislocation rings of the type shown in Fig. 1 may be generated in such a way that their contours coincides with the cross section of the prismatical punchings and the Burgers vector is along the axis of the prism. If a dislocation ring of this type moves parallel to the axis of the prism, the inside of the prism will be displaced relative to the outside along the boundary by one unit of slip. Moreover, dislocations of this type are constrained to move on the surface of the cylinder or prism since their projection normal to the axis of the prism must remain unchanged if the temperature is sufficiently low that diffusion cannot occur. For this reason we shall call them *prismatic dislocations*.

It is not difficult to see how the required prismatic dislocations may be generated. The slip planes bounding the surface of the prism, which is displaced by the indenter, intersect the surface of the specimen in the region of maximal shearing stress at the periphery of the area of contact between the indenter and crystal. Thus each such bounding plane becomes the seat of spirals or rings of dislocation which can be generated in a slip plane in the manner suggested by Frank and Read in the accompanying letter. The Burgers vector associated with the rings will be in the direction of the axis of the prism. Two rings (or spirals) which are generated on different planes that intersect on a line parallel to the axis of the prism can meet at the boundary line and interact to form segments of prismatic dislocations. Complete prismatic dislocations can be formed by combining rings from each of the bounding surfaces. An example s ishown schematically in Fig. 1. The rectangular prism $ABCDEFGH$ is pushed on the area $ABFE$, which is part of the surface of the specimen, coinciding with the area of contact of the indenter. This prism is bounded by four slip planes: $ABCD$, $ADEH$, $EFGH$- and $BCGF$. The dislocation rings 1, 2, 3, and 4 shown in Fig. 1a are generated on each of these four planes. As a result of the applied shearing stress, they expand within the four planes and may extend beyond the bounding surface of the prism, as shown in Fig. 1b. The rings on different intersecting faces, such as 1 and 2 on $ABCD$ and $ADHE$, respectively, may meet at points such as a and b in Fig. 1b. The cohesion of the lines is weak at junction points such as a and b and may break under the applied stress to form two prismatic dislocations α and β in Fig. 1c and dislocation rings such as s, t, u, and v in the same diagram. The last-named rings are bent so as to lie in two slip planes which meet at the edges of the prism. The prismatic dislocations α and β have opposite signs in the sense that α is the equivalent of an extra layer of atoms equal in thickness to the Burgers vector lying in a cross section of the prism, whereas β is the equivalent of a deficiency of one plane of atoms. The first dislocation may wander down the prism to the opposite face, where it will produce a jutting by one Burgers distance over the area ($CDHG$) representing the intersection of the prism with this surface. (In practice this surface could be much farther from $ABEF$, on a relative scale, than is shown.) On the other hand the prismatic dislocation β will emerge at the surface $ABEF$ where the force is applied and produce a depression of one Burgers distance. Bent dislocations of the type s, t, u, and v may produce localized plastic flow in the vicinity of the indenter. It may be noted that these dislocations would not be generated if the rings shown in Fig. 1a did not expand beyond the boundary of the prism, as illustrated in Fig. 1b, but met tangentially at the boundary lines.

Their presence does not appear to complicate the picture, however, for they will not interfere in any serious way with the generation of additional prismatic dislocations on the surface of the prism. It should be added that a single dislocation ring on one face of the prism may, on reaching the edge of this face, start moving along a second face which meets the first at the edge. For the ring will have the character of a Burgers or screw dislocation at the point of contact with the edge; a screw dislocation may move in any slip plane. In this way a single ring, generated on one face of the prism, may become wrapped around the prism and on meeting itself after complete circumnavigation, form two prismatic dislocations of opposite sign. Similarly a dislocation spiral in one face of the prism, or a pair of oppositely wound spirals which are joined, can produce an unlimited number of prismatic dislocations by wrapping around the surface of the prism.

Once a sequence of prismatic dislocations of the α-type have been started down the cylinder, they may transmit stresses to one another because of their mutual repulsion. Thus the force impressed on the prismatic dislocation nearest the surface $ABDF$ will be transmitted along the entire line to that nearest the opposite end of the prism. The prismatic dislocations α and β shown in Fig. 1c are composed of straight-line segments on each of the four bounding planes. Actually, the segments may be curved. The sequence of events portrayed here evidently could occur on the surfaces of two or more prisms whose axes lie along different slip directions, but which have a common intercept at the area where the indenter is applied.

The writer is indebted to Professor A. H. Cottrell for a stimulating discussion of this topic.

[1] A. Smakula and M. W. Klein, J. Opt. Soc. Am. **39**, 445 (1949).

Special and Magic Numbers as Factors in Nuclear Stability and Abundance*

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In the years 1915 to 1923, the following concept was introduced into nuclear science in about 20 papers.[1] The stability and abundances of nuclear species are determined largely by the relations of special numbers. This concept was received by Rutherford, and later by Goldschmidt, with much approval, but did not meet with so much favor from certain theorists.

It was stated that of all special numbers, 2 is preeminent. The later data of astronomers,[2] and of Goldschmidt,[3] Brown[4] and others indicates that the importance of the number 2 is greater than was supposed initially. In 1920 both Rutherford and the writer indicated that the nucleus consists of protons and neutrons, and Harkins indicated the composition of all nuclei as $(pn)_P n_I$, first expressed by the formula $(pep)_P(pe)_I$ in which it was stated "*pe* represents a neutron." P is the atomic and I the isotopic number.

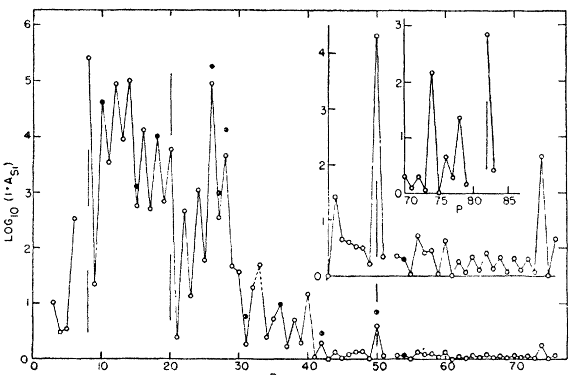

FIG. 1. Abundance of the elements in the meteorites: (A) as compared with that of silicon. The rare gases have been added by a comparison with the composition of the sun and stars. The upper right-hand corner presents values on expanded scales. Values for the ends of nuclear shells are represented by vertical lines. The most striking relative increase in abundance related to a magic number is that for $P=50$, which represents tin.

TABLE I. Atoms per million with even and odd protons.

Element	P even	P odd	P even	P odd	P_e/P_0
Carbon	6		177000		
Nitrogen		7		350000	
Oxygen	8		490000		
Fluorine		9		200	2950
Neon	10		100000		
Sodium		11		1020	60
Magnesium	12		20000		
Aluminum		13		2000	10.5
Silicon	14		22000		
Phosphorus		15		290	52
Sulfur	16		7800		
Chlorine		17		380	13
Argon	18		2200		
Potassium		19		180	11
Calcium	20		1800		
Scandium		21		0.4	2300
Titanium	22		58		
Vanadium		23		5.5	24
Chromium	24		210		
Manganese		25		170	120
Iron	26		40000		
Cobalt		27		220	100
Nickel	28		3000		
Copper		29		10	150
Zinc	30		3.6		
Gallium		31		1.4	3.3
Germanium	32		5.5		
Arsenic		33		10.7	100
Selenium	34		(2200?)		
Bromine		35		0.93	
Krypton	36				
Rubidium		37		0.10	
Strontium	38		0.9		
Yttrium		39		0.22	9.5
Zirconium	40		3.3		
Columbium		41		0.02	9.3
Molybdenum	42		0.42		

The number 2 is represented by the helium nucleus with its two neutrons and two protons. This species is estimated by astronomers[2] to be 70 times more abundant in the universe than the sum of all others. This excludes hydrogen from consideration since in this sense a proton is a simple nucleus.

Also every multiple of two is a special number. Thus each element which has in its nuclei an even number P_e of protons is in general very much more abundant than either of the adjacent elements with an odd number of protons. Figure 1 shows this but the relation is exhibited much better in Table I. The ratio of P_{even} to P_{odd} varies from *ca.* 3000 to 1.1, the latter for the ratio of Pd+Cd to Ag. (Note: Table I does not go so high as Ag due to lack of space.)

It is apparent that the abundance exhibits waves, in which in general high abundance for even elements are associated with relatively high abundances for odd elements, and peaks occur at oxygen and iron.

Figure 2 shows that in general the abundance of species with any certain even number of neutrons (N_e) is very much greater than that for the adjacent odd number, $N_e \pm 1$. Also the peaks and troughs in abundance lie in relative positions very similar for those for protons, with peaks at 2, 8, 20, 30 and presumably 82 neutrons.

For values of P or of N above 2 the effect on the abundance relations is much more striking in general for *even* numbers than for *magic* numbers. The latter are accompanied by a somewhat greater abundance than the adjacent even numbers.

The value 50 P (tin) exhibits strikingly the increase in abundance related to the end of the 50 P shell. The values 9 P and 21 P show a great lowering in abundance which occurs just after the respective shell (8 P or 20 P) ends. This same type of decrease in abundance occurs just after the closing of the 8, 20, 28 and 50, and 82 N shells, at 9, 21, 29, 51 and 83 N.

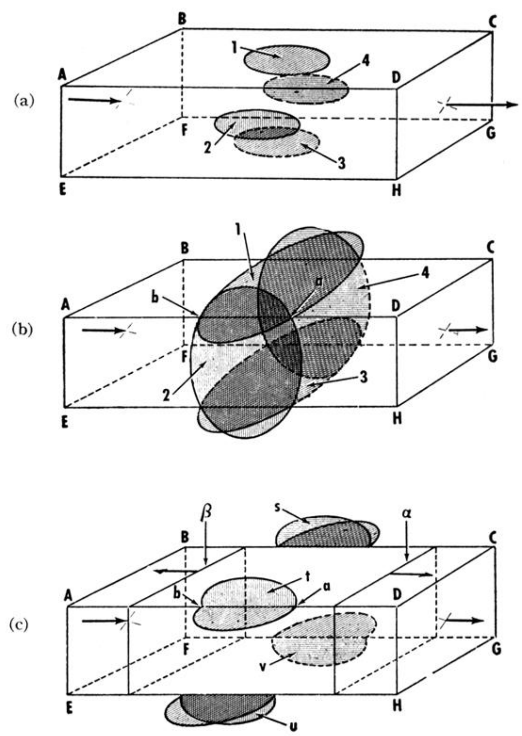

FIG. 1. Possible forms of dislocation rings.