

spectrometer analysis of the mercury. This was made on a Nier-type mass spectrometer by first carefully measuring the unavoidable small background of ordinary mercury with seven isotopes in the range 196 to 204. Then vapor was admitted from a small droplet of Hg^{198} by breaking an internal break-off seal. Measurements indicated no ordinary mercury in the sample and it is estimated that less than 0.1 percent of the 198 peak comes from this source. However, in addition to the large 198 peak there was a measurable increase in the 199 peak amounting to 0.16 percent \pm 0.06 of the 198 peak. In our experience, mercury hydride peaks have not been observed in mercury mass spectra, and it may well be that 199 comes from a secondary nuclear reaction. Neutron attachment to Au^{198} or Hg^{198} could produce the Hg^{199} . Inghram, Hess, and Hayden² have studied the isotopic constitution of ordinary mercury submitted to intense neutron irradiation and have established that most of the neutron absorption of mercury comes from the 199 isotope which is converted by an (n, γ) reaction to 200. This leaves the origin of 199 in our experiment open to question.

The mass spectrometer results indicate that the technique used in purifying the gold and recovering the mercury is excellent. The trace of 199 observed is too small to introduce any observable complexities of spectrum lines.

¹ "Light wave of mercury 198 as ultimate standard of length," Nat. Bur. of Stand. Tech. News Bull. 31, 133 (1947).

² Inghram, Hess, and Hayden, Phys. Rev. 71, 561 (1947).

On the Rate of Sintering of Metal Powders

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KÉ has reported recently¹ on experimental confirmation of Snoek's hypothesis² that, under stress, interstitially dissolved atoms in metals tend to become preferentially distributed in the lattice of the solvent metal. C. Zener³ has also observed this phenomenon in the case of a substitutional solid solution (70-30 alpha-brass). In this case the larger zinc atom distorts the copper lattice elastically. If two zinc atoms become neighbors, the distortion no longer has cubic symmetry; a stress is then able to orient the axis of the zinc pair in the direction of stress.

Frenkel⁴ has shown that the presence of a vacancy in a lattice introduces an elastic distortion which is the opposite of that introduced by adding a large solute atom. It is evident that a preferential distribution of pairs of vacancies should be observable under stress just as is a preferential distribution of solute atoms. In the case of zinc atoms some time is required for the establishment of the orientation, and the relaxation time of the phenomenon is related to the activation energy for diffusion of zinc in alpha-brass. Similarly, the rate of orientation of vacancy pairs must be related to the heat of activation for self-diffusion.

The relaxed orientation of vacancy pairs is perpendicular to a tensile stress.

It is believed that this mechanism may provide the atomistic explanation for the observation of Shaler and Wulff⁵ that the rate of sintering of copper powder can be predicted on the basis of a viscous flow of metal under the influence of surface tension, the viscosity being that resulting from the preferential self-diffusion of vacancies in the lattice under stress.

¹ Ting Sui KÉ, Phys. Rev. 73, 267 (1948).

² Snoek, Physica 8, 711 (1941).

³ C. Zener, Trans. A.I.M.E. 152, 122 (1943); Phys. Rev. 71, 34 (1947).

⁴ Frenkel, *Kinetic Theory of Liquids* (Clarendon Press, Oxford, 1946).

⁵ Shaler and Wulff, Phys. Rev. 72, 79 (1947)

The Energies of Alpha-Particles from Pu^{238} and Pu^{239}

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A STANDARD method for comparing the energies of two alpha-particles has been by comparison of the total ionization produced by each in an ion chamber. We find that the use of the vibrating-reed¹ electrometer can greatly increase the precision of such a method. In our apparatus the two samples to be compared are mounted on a turntable, so that by means of a magnetic control either may be brought into the active region of the ion chamber. The alpha-particles, by means of a collimating system consisting of holes in a thin plate, are directed parallel to the central electrode in a cylindrical ion chamber. The latter is connected to the vibrating-reed electrometer and a Brown strip-chart recorder. The sudden jump of the pen on the latter, produced by the ionization in the chamber from a single alpha-particle, may be of the order of four to five inches. Such jumps are very reproducible and may be read on the chart with good precision.

Some idea of the self-consistency of the method is given in Table I from an intercomparison of three samples of Po^{210} , Pu^{238} , and Pu^{239} . These samples were prepared by evaporation of solutions on platinum disks. For the preparation of these we are indebted to Miss Sylvia Warshaw and Mr. George Reed of our chemistry division. A detailed comparison of Pu^{239} against Po as a standard is shown in the first three columns of the table. For each run the samples were measured in turn in the chamber until more than a hundred electrometer jumps had been recorded for each sample. The counting rate was about two counts per minute. The ratio of the alpha-particle energies for the two samples was taken to be the ratio of the mean respective electrometer deflections. This assumption is probably justified within the narrow range of energies involved. On this basis, the values in column three for Pu^{239} were derived, the Po alpha-energy being taken as 5.298 Mev. The value of 5.137 for Pu^{239} includes a small correction of 0.002 for the energy lost in the collimating system. A comparison of Pu^{238} with Po in

TABLE I. Energy Comparisons.

Run	Gas in chamber	Energy for Pu ²³⁹ in Mev	Energy for Pu ²³⁸ comparison with Po ²¹⁰ (5.137 Mev)	Energy for Pu ²³⁸ from comparison with Pu ²³⁹ (5.137 Mev)
1	N ₂	5.13 _s		
2	N ₂	5.13 _s		
3	Argon	5.13 _s		
4 Samples reversed	Argon	5.13 _s		
5 Original position	Argon	5.14 _o		
6	Argon	5.14 _o		
7	Argon	5.13 _o		
Mean			5.137	5.49 _s 5.49 _o

argon gave the value in column four. This is the result of one extended run in argon. Finally, a cross comparison of Pu²³⁹ with Pu²³⁸ is shown in column five. This is the mean of two runs in argon. Here the alpha-energy for Pu²³⁹ was assumed to be 5.137 Mev, the value previously determined by comparison with Po. Although the almost exact agreement shown by the last two columns is undoubtedly somewhat fortuitous, the general consistency throughout the table cannot be considered so, since it is easily duplicated.

A series of runs with other samples, some deposited by electroplating instead of evaporation, is in good accord with the runs above. A weighted mean for all samples gives for Pu²³⁹ 5.140 Mev and for Pu²³⁸ 5.493 Mev. The consistency of the readings would indicate an error of about 0.1 percent. The ranges in air derived from these values and a range-energy curve² are 3.67 cm and 4.07 cm for Pu²³⁹ and Pu²³⁸, respectively. The agreement is good between these values and the values 3.68 cm and 4.08 cm from previous³ direct measurement of the ranges in air.

Measurement of the energies of various (*n, p*) reactions by this method are now in progress.

¹ Palevsky, Swank, and Grenchik, Rev. Sci. Inst. **18**, 298 (1947).

² Holloway and Livingston, Phys. Rev. **54**, 18 (1938).

³ Chamberlain, Gofman, Segrè, and Wahl, Phys. Rev. **71**, 529 (1947).

Phase Determination with the Aid of Implication Theory

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SINCE the implication diagram^{1,2} provides the locations of atoms in crystals, there must be a close similarity between a Fourier representation of the implication diagram and the Fourier representation of the projection of electron density of the crystal on the same plane. The relation between the coefficients of the two series can be ascertained in several ways. A straightforward way, which is not difficult in cases of low symmetry, is to expand $FF^*(hkl)$ and then separate $F(h'k'l')$ from the rest of the expansion. For symmetries other than $\bar{1}$ it is then possible to eliminate most (if not all) of the unsymmetrical components. This is illustrated here for symmetry 2 parallel to *c*. By a simple manipulation, the expansion of $FF^*(hkl)$ can

be arranged in the following form:

$$F_{hkl}^2 = \sum_i n_i f_{i,hkl}^2 + F_{hkl}(P_0) + F_{hkl}(P_z) \\ + \left(\frac{f_{1,hkl}^2}{f_{1,2h2k0}} \right) F_{2h2k0} + \sum_i \left(\frac{f_{i,hkl}^2}{f_{i,2h2k0}} - \frac{f_{1,hkl}^2}{f_{1,2h2k0}} \right) F_{2h2k0} \quad (1)$$

(a) (b) (c) (d) (e)

The expansion consists of five parts, which can be described in terms of the contribution of this term to the Patterson synthesis. (a) is a contribution to the origin peak, (b) represents the contribution on the Harker level to a non-Harker peak, and (c) represents a contribution to a general Patterson peak.

Term (c), which represents a very large part of the expansion, can be eliminated by the following manipulation: All terms are summed over *l* from *l* = -*L* to +*L*, and each side of the equation is multiplied by $\cos 2\pi(hx + ky)$. The left side of (1) then represents the hk contribution to a Harker synthesis on level zero, and the parts of the right side of (1) represent the hk contributions to Fourier syntheses of quasi-electron density representations. In the complete syntheses, (c) vanishes because it represents a section on level zero, where there is no "density." The only way for this to occur is for each term $\sum_l F(P_s)$ to vanish independently. This eliminates the term $\sum_l F_{hkl}(P_s) \times \cos 2\pi(hx + ky)$. All terms are now divided by $\cos 2\pi(hx + ky)$. There remains

$$\sum_{l=-L}^L F_{hkl}^2 = \sum_{l=-L}^L \sum_i n_i f_{i,hkl}^2 + \sum_{l=-L}^L F_{hkl}(P_0) \\ + \left(\frac{\sum_{l=-L}^L f_{1,hkl}^2}{f_{1,2h2k0}} \right) F_{2h2k0} \\ + \sum_i \left(\frac{\sum_{l=-L}^L f_{i,hkl}^2}{f_{i,2h2k0}} - \frac{\sum_{l=-L}^L f_{1,hkl}^2}{f_{1,2h2k0}} \right) F_{2h2k0} \quad (2)$$

(a) (b) (d) (e)

When non-Harker peaks can be recognized on the implication map, for example, by the non-appearance of satellites in certain symmetries,¹ term (b) can be allowed for. Relation (2) then provides the relation of *F*'s to *F*'s for twofold symmetry. The last term is a correction term which arises because all atoms do not scatter with the same power. When all atoms have about the same scattering power, as in many organic compounds and in many silicates, this term vanishes. In other cases, it can be evaluated from special position information or, more generally, from the locations of certain atoms provided by the implication diagram. Where these do not apply, then this term can be evaluated for its maximum value, in which case it sets determinable limits on the part of (2) which cannot be directly computed. Since the absolute values of the *F*'s are known, it should not be difficult in most cases to decide on phases of the *F*'s with the aid of (2).

Equalities of a similar nature exist for each Harker level of each symmetry. It should be noted that the phases of