THE STRUCTURE OF THE INTERMETALLIC COMPOUND Au_2Pb

BY

HARALD PERLITZ

TARTU 1934

K. Mattieseni trükikoda o.-ü., Tartu 1934.

CONTENTS: — (1) Introduction to and object of the present paper. (2) Preparation of the alloys. (3) The focussing cameras. (4) Reflexions from and unit cubes of the alloy $Au_{84\cdot8}\ Pb_{15\cdot2}$. (5) Reflexions from and unit cubes of alloys $Au_{66\cdot2}\ Pb_{33\cdot8}$ and $Au_{66\cdot0}\ Pb_{34\cdot0}$. (6) Reflexions from and unit cubes of the alloy $Au_{50\cdot5}\ Pb_{49\cdot5}$. (7) Narrowness of the single-phase region and number of atoms in the unit cube of Au_2Pb. (8) Possible space-groups for Au_2Pb and possible arrangements of atoms in them. (9) "Structure amplitudes" for Au_2Pb. (10) Comparison of calculated intensities with visually estimated intensities. (11) Distribution of atoms of Au and Pb in the unit cube. (12) Summary and conclusions.

1. In R. Vogel's equilibrium diagram of the system gold-lead [1]) two intermetallic compounds are met with. To one of them R. Vogel ascribes the stoichiometrical formula Au_2Pb, to the other the formula $AuPb_2$. To investigate the nature and the structure of the former compound, the compound Au_2Pb, four alloys ranging from 84·8 atomic per cent. of gold to 50·5 atomic per cent. of gold were examined by means of X-rays.

2. The alloys were prepared by melting together appropriate amounts of gold with lead "pro analysi" by Kahlbaum. This was performed at 900° C in silica tubes which were sealed up after being evacuated by an oil pump. They contained sufficient metal to yield ingots from 1 to 2 grams. To achieve a satisfactory mixing together of gold and lead the tubes with their liquid contents were shaken vigorously time and again. Finally the liquid melts were quenched in water at room temperature. The tempering of these quenched ingots was performed in glass tubes which were sealed up after being evacuated by an oil pump. The densities of the ingots were calculated from their weights in air and benzol. A part of the ingots was filed off, and their remainders polished for microscopical examination. The filings were recrystallized at the temperatures of tempering, powdered glass or graphite being added to prevent the grains

[1]) Z. anorg. Chem. 45. 1905. 11 to 23.

from sticking together. Data on the composition, tempering, recrystallisation, density, and appearance of these alloys are collected in Table 1.

Table 1.

Data on composition, tempering, recrystallisation, density, and appearance of examined alloys.

Composition: atomic per cent. *)		Tempering:		Temperature of recrystallisation °C	Density g cm^{-3}	Appearance	
Au	*Pb*	temperature °C	duration days				
84·8	15·2	370	$4\frac{3}{4}$	370	$17{\cdot}1_5$	golden yellow	with pores all over the surface
66·2	33·8	390	16	395	$15\,6_8$	yellowish	
66·0	34·0	220	3	**)	$15{\cdot}6_2$	yellowish	
50·5	49·5	220	$4\frac{3}{4}$	220	$14{\cdot}3_5$	grey	

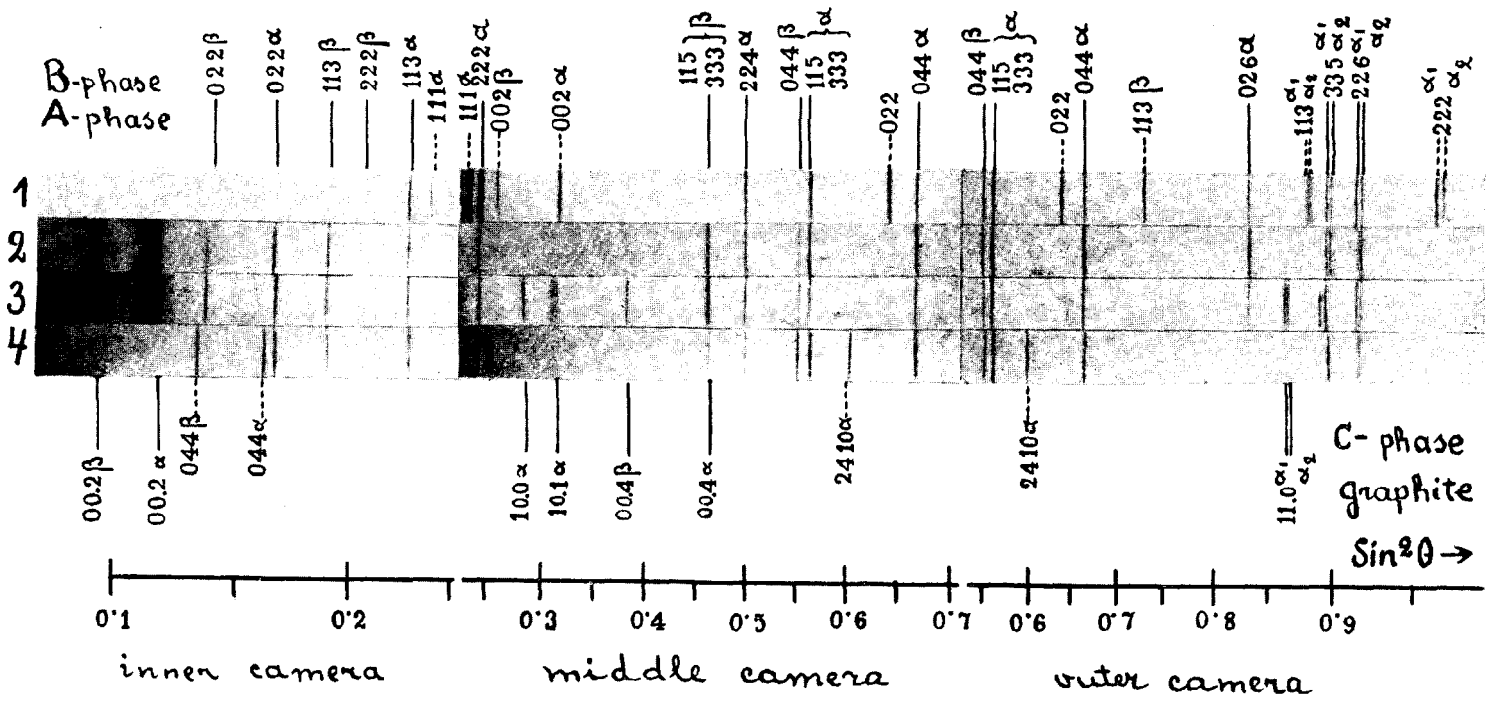
*) Assuming as atomic weight 197·2 and 207·2 for *Au* and *Pb* respectively.

**) Recrystallisation omitted since not the ingot but filings from it were subjected to tempering.

3. The filings of every alloy were exposed to *Cr*-radiation using consecutively three different focussing cameras of Phragmén's[1] type. One of these cameras covered the range of Θ $16^0 \leqslant \Theta \leqslant 30^0$, the other the range $29^0 \leqslant \Theta \leqslant 57^0$, and the last the range $46^0\frac{1}{2} \leqslant \Theta \leqslant 82^0\frac{1}{2}$, Θ designating the angle of reflexion. These cameras will be referred to as the *inner*, the *middle*, and the *outer* camera respectively. They had been calibrated by taking films of powdered sodium chloride with *K*-radiation of either iron or chromium. For the purpose of calibration the following values have been adopted: 5·6280 Å for the length of the edge of the unit cube of sodium chloride; 1·9323 Å and 1.9365 Å for the α_1- and α_2-radiation of iron respectively; 2·2848 Å and 2·2890 Å for the α_1- and α_2-radiation of chromium respectively. Photograms of the four investigated alloys are reproduced in Figures 1 to 4 and all data relating to them collected in Tables 2 to 5.

4. The reflexions from the alloy $Au_{84{\cdot}8}$ $Pb_{15{\cdot}2}$ in Table 2 are grouped into two mutually exclusive groups. The reflexions

[1]) Arne F. Westgren, Trans. Amer. Inst. Min. Met. Engineers, New York Meeting, February, 1931, preprint p. 2 to 6.



Figures 1 to 4.

Powder photographs of alloys $Au_{84\cdot8}\,Pb_{66\cdot2}$ (1), $Au_{66\cdot2}\,Pb_{33\cdot8}$ (2), $Au_{66\cdot0}\,Pb_{34\cdot0}$ (3), and $Au_{50\cdot5}\,Pb_{49\cdot5}$ (4). The lines of the intermetallic compound Au_2Pb (*B*-phase) are common to all the photographs. The additional lines are caused by gold (*A*-phase) in the uppermost photographs, graphite in the middle photographs and the second intermetallic compound (*C*-phase) in the lowest photographs.

Table 2.

Data for lines due to reflexions from an alloy containing 84·8 atomic per cent. *Au* and 15·2 atomic per cent. *Pb*.

1 $10^2 \times \frac{\sin^2\Theta}{Q^2}$	2 Q^2	3 λ	4 I	5 $\sin^2\Theta$	6 I	7 λ	8 Q^2	9 $10^3 \times \frac{\sin^2\Theta}{Q^2}$
				inner camera				
				0·1664	*vf*	α	8	20·80
				0·1894	*vf*	β	11	17·22
6·590	3	β	*vf*	0·1977				
				0·2289	*f*	α	11	20·80
7·987	3	α	*f*	0·2396				
				middle camera				
7·970	3	α	*st*	0·2391				
				0·2486	*m*	α	12	20·72
6·628	4	β	*vf*	0·2651				
7·998	4	α	*m*	0·3199				
				0·3323	*vf*	α	16	20·78
				0·4138	*vf*	β	24	17·25
				0·4660	*f*	β	27	17·25
				0·4995	*f*	α	24	20·82
6·649	8	β	*f*	0·5319				
				0·5523	*vf*	β	32	17·28
				0·5628	*m*	α	27	20·86
8·018	8	α	*m*	0·6414				
				0·6663	*m*	α	32	20·84
				outer camera				
				0·5529	*f*	β	32	17·29
				0·5629	*st*	α	27	20·86
7·904	8	α	*st*	0·6323				
				0·6678	*st*	α	32	20·88
6·652	11	β	*f*	0·7317				
				0·7438	*vf*	β	43	17·30
				0·7613	*vf*	β	44	17·31
6·654	12	β	*vf*	0·7985				
				0·8340	*f*	α_1	40	20·84
				0·8370	*vf*	α_2	40	20·92
8·022	11	α_1	*vst*	0·8825				
8·061	11	α_2	*m*	0·8867				
				0·8964	*m*	α_1	43	20·86
				0·9000	*f*	α_2	43	20·92
				0·9176	*m*	α_1	44	20·84
				0·9213	*f*	α_2	44	20·92
8·028	12	α_1	*m*	0·9632				
8·051	12	α_2	*vf*	0·9662				

← *A*-phase face-centred cubic $a = (4·036 \pm 0·001)$ Å

B-phase face-centred cubic $a = (7·912 \pm 0·001)$ Å →

Q^2 sum of squares of Millerian indices;

λ type of Cr-K radiation, following values being adopted: $\lambda_{\alpha_1} = 2·285$ Å, $\lambda\alpha_2 = 2·289$ Å, $\lambda_\beta = 2·074$ Å;

I estimated intensity: *vf* = very faint, *f* = faint, *m* = medium, *st* = strong, *vst* = very strong;

Θ angle of reflexion;

a length of the edge of the unit cube.

detailed in columns 1 to 4 are present only in films of this particular alloy. The measured positions and estimated intensities of these lines are in accord with a face-centred cubic lattice like that of gold (1). The length of the edge of the unit cube of this lattice is found to be $(4{\cdot}036 \pm 0{\cdot}001)$ Å, as calculated from the four most deviated lines due to resolved α-doublets. This value is less by about 1 per cent. than the values 4·0700 Å and $4{\cdot}071_1$ Å for the length of the edge of the unit cube of pure gold (2). It is therefore concluded that these lines are due to the lattice of gold in which some atoms of gold are substituted by atoms of lead. This lattice is referred to as the lattice of the *A*-phase.

The lines detailed in columns 6 to 9 are common to films of all the four alloys investigated. The sum of the squares of the Millerian indices for these lines is suggestive of a cubic structure with a face-centred unit cube (3). The length of the edge of this unit cube is found to be $(7{\cdot}912 \pm 0{\cdot}001)$ Å as calculated from the six most deviated lines due to resolved α-doublets. This structure will be referred to as the structure of the *B*-phase.

5. All lines on the films from the alloy $Au_{66{\cdot}2}Pb_{33{\cdot}8}$ and the alloy $Au_{66{\cdot}0}Pb_{34{\cdot}0}$ in Tables 3 and 4 respectively are grouped into two groups. All the lines detailed in columns 1 to 3 are due to the admixture of powdered graphite to the filings of these alloys, this being checked by taking special films of the powdered graphite. All the lines detailed in columns 5 to 8 are lines of the *B*-phase, the presence of which has been already established from the data of Table 2. The length of the edge of the unit cube of the *B*-phase is found to be $(7{\cdot}911 \pm 0{\cdot}002)$Å and $(7{\cdot}912 \pm 0{\cdot}002)$ Å as calculated from the data for the most deviated lines due to resolved α-doublets in Tables 3 and 4 respectively. Besides the lines which are detailed in columns 1 to 3 and 5 to 8 as due to reflexions from graphite and the *B*-phase respectively five spots are found on the photograph of

1) P. Scherrer and Richard Zsigmondy, Kolloidchemie, 3rd edition, p. 400; L. W. McKeehan, Phys. Rev. 20. 1922. 428; A. Huber, Physikal. Z. 25. 1924. 44; Wheeler P. Davey, Physic. Rev. 25. 1925. 759; Sven Holgersson, Ann. Physik 79. 1926. 38.

2) G. Sachs and J. Weerts, Z. Physik 60. 1930. 489, and E. A. Owen and I. Iball, Phil. Mag. 13. 1932. 1020 respectively.

3) L. W. McKeehan, Amer. Journ. Sci. 17. 1929. 550.

Table 3.

Data for lines and spots due to reflexions from an alloy containing 66·2 atomic per cent. *Au* and 33·8 atomic per cent. *Pb*.

1	2	3	4	5	6	7	8
hkl	λ	*I*	$\sin^2\Theta$	*I*	λ	Q^2	$10^3 \times \frac{\sin^2\Theta}{Q^2}$
			inner camera				
002	β	*vst*	0·0959				
002	α	*vst*	0·1166				
			0·1382	*vf*	β	8	17·28
			0·1666	*f*	α	8	20·83
			0·1898	*f*	β	11	17·25
			0·2065	*vf*	β	12	17·21
			0·2289	*m*	α	11	20·81
			0·2492	*f*	α	12	20·77
			middle camera				
			0·2507	*m*	α	12	20·89
101	β	*vf*	0·2595				
100	α	*m*	0·2898				
101	α	*m*	0 3186				
			0·3342	*vf*	α	16	20·88
004	β	*f*	0·3857				
			0·4157	*vf*	β	24	17·32
004	α	*st*	0·4660	*st*	β	27	17·26
			0·5015	*f*	α	24	20·90
			0·5538	*vf*	β	32	17·30
			0·5638	*m*	α	27	20·88
			0·6682	*m*	α	32	20·88
			outer camera				
			0·5529	*f*	β	32	17·28
			0·5618	*m*	α_1	27	20.81
			0·5641	*f*	α_2	27	20·92
			0·6485	*vf*			
			0·6668	*f*	α_1	32	20·84
			0·6701	*vf*	α_2	32	20·94
110	β	*vf*	0·7185				
			0·7443	*vf*	β	43	17·31
			0·7608	*vf*	β	44	17·29
			0·7823	*vf*			
			0·8349	*f*	α_1	40	20·87
			0·8375	*vf*	α_2	40	20·94
110	α_1	*m*	0·8655				
110	α_2	*f*	0·8684				
			0·8927	*m*			
			0·8955	*f*			
			0·8971	*m*	α_1	43	20·86
			0·9000	*f*	α_2	43	20·93
			0·9183	*m*	α_1	44	20·87
			0·9213	*f*	α_2	44	20·93
			0·9817	*st*			

← graphite

B-phase → face-centred cubic $a = (7{\cdot}911 \pm 0{\cdot}002)$ Å

hkl Millerian indices.

hkl

The figures set in nonpareil are not due to lines but to spots that are present only amongst lines due to the alloy $Au_{66\cdot2}Pb_{33\cdot8}$.

Table 4.

Data for lines due to reflexions from an alloy containing 66·0 atomic per cent. *Au* and 34·0 atomic per cent. *Pb*.

1	2	3	4	5	6	7	8
hkl	λ	*I*	$\sin^2\Theta$	*I*	λ	Q^2	$10^8 \times \frac{\sin^2\Theta}{Q^2}$
			inner camera				
002	β	*m*	0·0958				
002	α	*vst*	0·1154				
			0·1386	*vf*	β	8	17·16
			0·1671	*f*	α	8	20·92
			0·1900	*f*	β	11	17.28
			0·2065	*vf*	β	12	17·20
			0·2289	*m*	α	11	20·82
			0·2504	*f*	α	12	20·88
			middle camera				
			0·2490	*st*	α	12	20·78
100	α	*vf*	0·2876				
101	α	*vf*	0·3158				
			0·3328	*vf*	α	16	20·78
004	β	*vf*	0·3848				
			0·4152	*vf*	β	24	17·30
004	α	*m*	0·4650	*m*	β	27	17·24
			0·5005	*m*	α	24	20·86
			0·5538	*f*	β	32	17·32
			0·5643	*st*	α	27	20·88
			0·6687	*st*	α	32	20·90
			outer camera				
			0·5523	*f*	β	32	17·30
			0·5629	*st*	α	27	20·84
			0·6678	*st*	α	32	20·88
			0·6928	*vf*	β	40	17·32
			0·7454	*vf*	β	43	17·35
			0·7613	*vf*	β	44	17·32
			0·8331	*f*	α_1	40	20·83
			0·8370	*f*	α_2	40	20·92
110	α	*f*	0·8655				
			*0·8964	*m*	α_1	43	20·85
			*0·9000				
			*0·9026	*m*	α_2	43	20·92
			*0·9176	*m*	α_1	44	20·85
			*0·9209				
			*0·9236	*m*	α_2	44	20·94

graphite

B-phase
face-centred cubic
$a = (7{\cdot}912 \pm 0{\cdot}002)$ Å

* These lines of the α-doublet are broadened to such an extent that they merge into one another.

Table 5.

Data for lines due to reflexions from an alloy containing 50·5 atomic per cent. *Au* and 49·5 atomic per cent. *Pb*.

1 $10^3 \times \frac{\sin^2\Theta}{Q^2}$	2 Q^2	3 λ	4 I	5 $\sin^2\Theta$	6 I	7 λ	8 Q^2	9 $10^3 \times \frac{\sin^2\Theta}{Q^2}$
				inner camera				
				0·1334	*f*	β	32	4·170
17·11	8	β	*vf*	0·1369				
				0·1606	*m*	α	32	5·019
20·71	8	α	*f*	0·1657				
17·18	11	β	*f*	0·1889				
17·21	12	β	*f*	0·2065				
				0·2107	*f*	α	42	5·017
20·69	11	α	*st*	0·2276				
				0·2416	*f*	α	48	5·034
20·71	12	α	*f*	0·2485				
				middle camera				
				0·2400	*vf*	α	48	5·000
20·57	12	α	*f*	0·2469				
				0·2582	*f*	α	51	5·062
				0·4535	*vf*	α	90	5·039
17·24	27	β	*vf*	0·4655				
				0·4885	*f*	α	97	5·035
20·84	24	α	*f*	0·5000				
17·26	32	β	*f*	0·5523				
20·84	27	α	*m*	0·5628				
				0·6012	*f*	α	120	5·008
20·85	32	α	*f*	0·6673				
				outer camera				
17·27	32	β	*f*	0·5526				
20·85	27	α	*m*	0·5633				
				0·6024	*f*	α	120	5·020
20·84	32	α	*m*	0·6669				
17·38	43	β	*vf*	0·7472				
				0·7826	*vf*	α	155	5·049
				0·7972	*vf*	α	158	5·046
20·88	40	α	*vf*	0·8353				
				0·8769	*vf*	α	174	5·040
20·91	43	α_1	*f*	0·8993				
20·99	43	α_2	*vf*	0·9030				
20·90	44	α_1	*f*	0·9200				
20·96	44	α_2	*vf*	0·9231				

← *B*-phase face-centred cubic $a = (7{\cdot}903 \pm 0{\cdot}002)\,\text{Å}$

C-phase simple cubic $a = 16{\cdot}14\,\text{Å}$ →

the outer camera dealt with in Table 3. The $\sin^2\Theta$ due to these spots are printed in nonpareil type.

6. The lines on the films from the alloy $Au_{50\cdot5}Pb_{49\cdot5}$ in Table 5 are again grouped into two groups. The lines detailed in columns 1 to 4 are due to the B-phase. The length of the edge of the unit cube in this alloy is found to be $(7\cdot903\pm0\cdot002)\mathring{A}$ as calculated from the four data for the most deviated lines due to resolved α-doublets. The lines detailed in columns 6 to 9 are to be attributed to the next intermetallic compound, $AuPb_2$, of the system gold-lead. They are suggestive of a cubic structure with a unit cube of the simple type. The length of edge of this unit cube is found to be $16\cdot14\ \mathring{A}$.

7. The values for the length of the edge of the unit cubes are collected in Table 6. The length of the edge of the unit

Table 6.

Data for lengths a of the edge of unit cubes.

Atomic per cent.		Phase	a in $\mathring{A}$
Au	Pb		
84·8	15·2	$A+B$	$4\cdot03_6$; $7\cdot91_2$
66·2	33·8	B	$7\cdot91_1$
66·0	34·0	B	$7\cdot91_2$
50·5	49·5	$B+C$	$7\cdot90_3$; $16\cdot1_4$

The length for the edge of the unit cube of the B-phase does not change appreciably.

cube of the B-phase does not change in the interval from 15·2 to 34·0 atomic per cent. of lead, and it decreases only very slightly, at about $1^1/_4$ per mill., in the interval from 34·0 to 50·5 atomic per cent. of lead. Therefore, the single-phase region of the B-phase must be very narrow and it may be assumed that the alloys $Au_{66\cdot2}Pb_{33\cdot8}$ and $Au_{66\cdot0}Pb_{34\cdot0}$ lie in the single-phase region or at its border. Therefore, the number of atoms in the unit cubes of these alloys may be calculated. From their densities and the lengths of the edge of their unit cubes, we find $23\cdot4_6$ atoms for the unit cube of the alloy $Au_{66\cdot2}Pb_{33\cdot8}$ and $23\cdot3_7$ atoms for the unit cube of the alloy $Au_{66\cdot0}Pb_{34\cdot0}$. The number of atoms in the unit cube should not be less than these figures and it must be an integer. Therefore, it will be assumed that

the unit cube contains 24 atoms; this gives as density $15{\cdot}3_2$ and $15{\cdot}2_2$ for the alloys $Au_{66{\cdot}2}Pb_{33{\cdot}8}$ and $Au_{66{\cdot}0}Pb_{34{\cdot}0}$ respectively instead of $15{\cdot}6_8$ and $15{\cdot}6_2$ respectively.

8. The present and absent lines of the types *OOh*, *Ohh*, and *hhh* are listed in Table 7. From Table 7 it is inferred that the

Table 7.

Present and absent lines in spectra of the *B*-phase.

OOh	*Ohh*	*hhh*
003 —	022+	222+
004+	033 —	333+
005 —	044+	
006 —		

+ = present, — = absent.

This table suggests that the possible atomic arrangements of the *B*-phase are those of the space group O_h^7, or O^4, or T_h^4.

space-group of the intermetallic compound Au_2Pb is either O_h^7, or O^4, or T_h^4 [1]. In the space-group O_h^7, O^4, and T_h^4 the 24 atoms of the unit cube occupy one of the four special positions [2]: —

(1) $16\,(b) + 8\,(f)$,
(2) $16\,(b) + 8\,(g)$,
(3) $16\,(c) + 8\,(f)$,
(4) $16\,(c) + 8\,(g)$.

But a translation along the diagonal of the unit cube for half its length brings the positions of arrangement (1) and arrangement (2) into coincidence with the positions of arrangement (4) and arrangement (3) respectively. Hence, only arrangement (1) and arrangement (2) need to be discussed.

---

[1]) A. Schleede und E. Schneider, Röntgenspektroskopie und Kristallstrukturanalyse, Walter de Gruyter & Co, Berlin und Leipzig, 1929, vol. 2, p. 237.

[2]) Ralph W. G. Wyckoff, An analytical expression of the results of the theory of space-groups, The Carnegie Institution of Washington, Washington, 1922, pp. 176 to 177, 144, 134, 125, 105 to 106, 104.

9. The "structure amplitude" for either of these arrangements may be written

$$F(hkl) = f_{16}F_{16} + f_8F_8,$$

$f_{16}f_8$ where f_{16} and f_8 are the atomic scattering factor for atoms
F_{16} located in position 16(b) and 8(g) or 8(f) respectively, and F_{16}
F_8 and F_8 the "structure amplitude" for the arrangement of 16 and 8 equivalent points respectively. The atomic scattering factors for gold and lead differ by less than 4 per cent., therefore, for our purpose the "structure amplitude" may be calculated as well from the simpler sum

$F(hkl)$ proportional to $F_{16} + F_8$

$$= \sum_1^{16} exp\ 2\pi i \left\{16\,(b)\right\} + \sum_1^{8} exp\ 2\pi i \left\{8\,(f)\ \text{or}\ 8\,(g)\right\}.$$

This summation yields for the "structure amplitude" the expression

$$(1)\quad 1 + (-1)^{\frac{h+k}{2}} + (-1)^{\frac{h+l}{2}} + (-1)^{\frac{k+l}{2}} + (\pm 1)^h . 2\,cos\frac{\pi}{4}(h+k+l),$$

where $(+1)^h$ is to be taken in case of arrangement (1) and $(-1)^h$ in case of arrangement (2).

10. The intensities of the reflexions may be expressed by

$$(2)\qquad \frac{1 + cos^2 2\Theta}{sin^2\Theta . cos\Theta} . z . F^2,$$

z where z is the relative number of reflecting planes and one of the varieties of the expression (1) is to be substituted for F. If the "structure amplitude" with $(+1)^h$ is substituted in the expression (2) then the calculated intensities do not agree with the visually estimated intensities. Hence arrangement (1) is incompatible with the observed intensities. On the contrary, the intensities calculated by using the "structure amplitude" with $(-1)^h$ agree closely with the visually estimated intensities as shown by Table 8 and Figure 5. Whence the positions of the atoms of the B-phase of the intermetallic compound Au_2Pb are those of arrangement (2), *viz.* 16 (b) and 8 (g). This arrangement is illustrated by Figure 6.

Table 8.

Calculated and visually estimated intensities of reflexions for alloys $Au_{66\cdot2}Pb_{33\cdot8}$ and $Au_{66\cdot0}Pb_{34\cdot0}$.

Q^2	hkl	Intensities						
		calculated	visually estimated					
			$Au_{66\cdot2}Pb_{33\cdot8}$			$Au_{66\cdot0}Pb_{34\cdot0}$		
			I	M	O	I	M	O
8	022	36·4	f			f		
11	113	145	m			m		
12	222	59·1	f	m		f	st	
16	004	7·86		vf			vf	
19	133	2·24		abs.			abs.	
20	024	0		abs.			abs.	
24	224	21·7		f			m	
27	115 + 333	82·1		m	$m+f$		st	st
32	044	100		m	$f+vf$		st	st
35	135	4·22			abs.			abs.
36	006 + 244	0			abs.			abs.
40	026	16·5			$f+vf$			$f+f$
43	335	130			$m+f$			$m+m$
44	226	202			$m+f$			$m+m$

I = inner, M = middle, O = outer camera;
abs. = absent; vf = very faint, f = faint, m = medium, st = strong.

For resolved doublets the intensities of each component are stated separately, the quotation before and after the sign + referring to the α_1-and α_2-component respectively. Calculated and visually estimated intensities agree sufficiently closely.

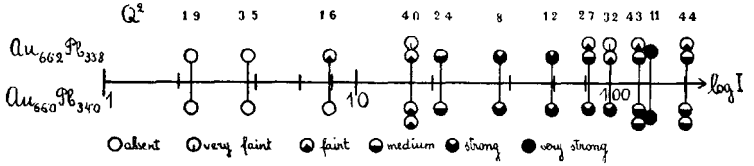


Figure 5.

Chart of calculated and visually estimated intensities for reflexions due to alloy $Au_{66\cdot2}$ $Pb_{33\cdot8}$ and alloy $Au_{66\cdot0}$ $Pb_{34\cdot0}$ respectively.

The value for the calculated intensity of every reflexion is indicated by the position of the corresponding vertical line which cuts the horizontal logarithmic scale of intensities. The visually estimated intensity of every reflexion is marked by an appropriately shadowed circle at the upper end of this vertical line for the alloy $Au_{66\cdot2}$ $Pb_{33\cdot8}$ and at the lower one for the alloy $Au_{66\cdot0}$ $Pb_{34\cdot0}$. The visual estimations of the intensities for reflexions from the inner and middle camera are reduced to those from the outer camera. The chart shows that the calculated values of the intensities are corroborated by visual estimations.

11. The same arrangement of atoms has been found for the intermetallic phase $MgCu_2$ [1] and KBi_2 [2] with the atoms of *Cu* or *Bi* in positions 16(*b*) and the atoms of *Mg* or *K* in positions 8(*g*). The mode of distribution of the atoms of *Au* and *Pb* in positions 16(*b*) and 8(*g*) cannot be deduced from visually estimated intensities, because the atomic scattering factors of gold and lead differ only slightly. But it may be deduced from

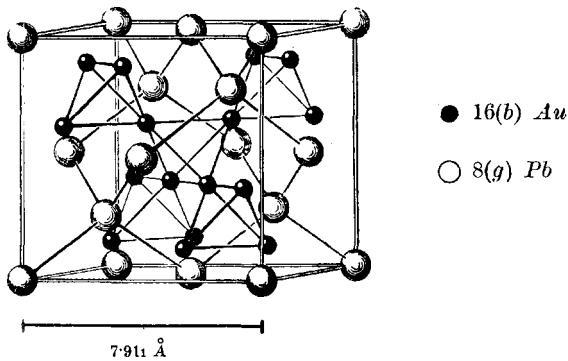


Figure 6.

Positions of atoms in the unit cube of the intermetallic compound Au_2Pb.

From the intensities of the reflexions it is concluded that the atoms of *Au* and *Pb* are distributed among the positions on the figure. From the atomic diameters it is concluded that the positions 16 (*b*) are occupied by atoms of *Au* and the positions 8 (*g*) by those of *Pb*. (Adapted from E. Zintl and A. Harder, Z. physikal. Chem. B. 16. 1932. 211.)

considerations of the atomic diameters. In arrangement 16(*b*) the least distance between two points is 2·797Å which is only a little less than 2·878Å, the least distance of two atoms in the unit cube of gold; in arrangement 8(*g*) the least distance between two points is 3·426Å which is a little less than 3·494Å, the least distance of two atoms in the unit cube of lead; lastly, the least distance between two points of which one belongs to arrangement 16(*b*) and the other to arrangement 8(*g*) is 3·273Å which is a little less than $\frac{1}{2}$ (2·878Å + 3·494Å) = 3·186Å. These figures suggest that all the positions of arrangement 16(*b*) are occupied

[1]) J. B. Friauf, J. Amer. Chem. Soc. 49. 1927. 3109; A. Runquist, A. Arnfelt and F. Westgren, Z. anorg. Chem. 175. 1928. 44.

[2]) E. Zintl and A. Harder, Z. physikal. Chem. B. 16. 1932. 211.

by atoms of gold and all those of arrangement 8(*g*) by atoms of lead. Whence the co-ordinates of the 16 atoms of gold are: —

$$\tfrac{1}{8}\tfrac{1}{8}\tfrac{1}{8};\ \tfrac{5}{8}\tfrac{5}{8}\tfrac{1}{8};\ \tfrac{5}{8}\tfrac{1}{8}\tfrac{5}{8};\ \tfrac{1}{8}\tfrac{5}{8}\tfrac{5}{8};\ \tfrac{1}{8}\tfrac{7}{8}\tfrac{7}{8};\ \tfrac{5}{8}\tfrac{3}{8}\tfrac{7}{8};\ \tfrac{5}{8}\tfrac{7}{8}\tfrac{3}{8};\ \tfrac{1}{8}\tfrac{3}{8}\tfrac{3}{8};$$
$$\tfrac{7}{8}\tfrac{1}{8}\tfrac{7}{8};\ \tfrac{3}{8}\tfrac{5}{8}\tfrac{7}{8};\ \tfrac{3}{8}\tfrac{1}{8}\tfrac{3}{8};\ \tfrac{7}{8}\tfrac{5}{8}\tfrac{3}{8};\ \tfrac{7}{8}\tfrac{7}{8}\tfrac{1}{8};\ \tfrac{3}{8}\tfrac{3}{8}\tfrac{1}{8};\ \tfrac{3}{8}\tfrac{7}{8}\tfrac{5}{8};\ \tfrac{7}{8}\tfrac{3}{8}\tfrac{5}{8};$$

and those of the 8 atoms of lead are: —

$$\tfrac{1}{2}00;\ 0\tfrac{1}{2}0;\ 00\tfrac{1}{2};\ \tfrac{1}{2}\tfrac{1}{2}\tfrac{1}{2};\ \tfrac{3}{4}\tfrac{1}{4}\tfrac{1}{4};\ \tfrac{1}{4}\tfrac{3}{4}\tfrac{1}{4};\ \tfrac{1}{4}\tfrac{1}{4}\tfrac{3}{4};\ \tfrac{3}{4}\tfrac{3}{4}\tfrac{3}{4}.\ (^1)$$

12. An X-ray examination of filings of four *Au-Pb* alloys confirms the existence of an intermetallic compound with a very narrow single-phase region in the vicinity of the composition of 66·6 atomic per cent. *Au* and 33·4 atomic per cent. *Pb*. The position of reflexions in cameras of the focussing type suggest a face-centred cubic lattice with 7·91$_1$ $\mathring{A}$ for the length of the edge of its unit cube and 24 atoms in it. Absent reflexions suggest one of the space-groups O_h^7, O^4, and T_h^4. A comparison of calculated intensities with visually estimated intensities gives for the positions of atoms in the unit cube the arrangement 16(*b*) and 8(*g*), in Wyckoff's notations. The dimensions of atomic diameters suggest that the atoms of *Au* occupy the positions of arrangement 16(*b*) and the atoms of *Pb* those of arrangement 8(*g*), *i. e.* the structure of Au_2Pb is of the same type as the structure of $MgCu_2$ and KBi_2.

The experimental part of this investigation was carried out in the Institute of General and Inorganic Chemistry at the Stockholm University and the Metallographic Institute in Stockholm. The author wishes to thank Prof. A. Westgren, Metallographer G. Phragmén, and Prof. C. Benedicks for their kind hospitality and advice.

Department of Physics.
The University.
Tartu.
August 31st, 1934.

---

1) Ralph R. G. Wyckoff, An analytical expression of the results of the theory of space-groups, The Carnegie Institution of Washington, Washington, 1922, 104 to 106.