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THE MINERAL CONTENT OF SOME YEMENI HONEYS
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As the result of carrying out a series of numerical experiments, the following estimation of the relative error of thermophysical liquid characteristics defining was obtained, subject to how accurate the temperatures are measured and in what way these temperature characteristics are used in calculation.

Absolute error of temperature measurement *ΔT, ˚C*	Relative error of defining thermal conductance λ, %			Relative error of defining thermal diffusivity a, %		
	On T_2, T_3	On T_2, T_b	On T_3, T_b	On T_2, T_3	On T_2, T_b	On T_3, T_b
0,005	2,78	0,18	0,18	7,18	0,35	0,35
0,01	5,55	0,36	0,35	14,71	0,69	0,69
0,05	27,69	1,83	1,74	83,22	3,45	3,31
0,1	-	3,77	3,50	-	6,91	6,70

As it is seen from the table, the least error is obtained when the temperature T_3 is used on the last but one section of the measuring part and the bulk liquid temperature T_b at a sensor output. In whole, judging by the table, it is possible to assume that the relative error of thermal conductance defining makes up about 3…5% and the error of thermal diffusivity defining makes up about 7…8 diffusivity %.

Bibliography

1. **Ponomarev S. V.** Methods and Devices for the Measurement of Effective Thermophysical Characteristics of Technological Liquid Flows / S. V. Ponomarev, S. V. Mishchenko. - Tambov: TSTU, 1997. - 249 p.
2. **Ponomarev S. V.** Measurements of Thermophysical Properties by Laminar Flow Methods / S. V. Ponomarev, S. V. Mishchenko, T. F. Irvine. - New-York: Begell House Inc., 2001. - 250 p.
3. **Petukhov B. S.** Heat Exchange and Heat Resistance in the Laminar Liquid Flow in Tubes. - M.: Energy, 1967. - 411 p.
4. **Samarskyi A. A.** The Theory of Difference Schemes. - M.: Science, Chief Editor Phys.-Math. Lit., 1989. – 3rd edition. - 616 p.
5. **Patankar S.** Numerical Methods of Solution of Heat Exchange and Fluid Dynamic Problems / Transl. from Engl. - M.: Energoatomizdat, 1984. - 152 p.
6. **Khanuni S. S.** Modeling of the Measurement Device for Measuring Thermophysical Characteristics of Liquid by Means of Laminar Mode / S. S. Khanuni, A. N. Dryazgov, S. V. Ponomarev // Vestnik TSTU. - 2003. - V. 9. - № 4. - P. 619-631.

THE MINERAL CONTENT OF SOME YEMENI HONEYS

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Introduction

The mineral and trace elements content in honey samples could give an indication of environmental pollution and herewith also an indication of the geographical origin of honey [Anklam 1998].

Some areas, in where there is a human activity, have heavy metal pollution due to different sources such as home wastes, straw and traffic wastes. Plant which grown under the effects of these pollutants can contain different range of heavy metals. High heavy metal concentrations in plant body can cause increasing of heavy metal concentrations in honey bee because bees collect pollens from different kind of flowers [Demirezen and Aksoy 2005].

The target of this investigation was to verify the content of some mineral elements in six kinds of Yemeni honeys.

Materials and Methods

Chemicals

All chemicals were ultra pure grade. HNO_3 (Merck/Germany); H_2O_2 (BDH/England); H_2O (Milli-Q UV- Plus system, Millipore Corporation, USA).

Standard Working Solutions

1. Multi-element calibration standard (Ag, Al, As, Ba, Be, Bi, Ca, Cd, Co, Cr, Cs, Cu, Fe, Ga, Hg, In, K, Li, Mg, Mn, Na, Ni, Pb, Rb, Se, Sr, Ti, U, V, Zn). Matrix per volume: 5% HNO_3 per 100 ml. Concentration of elements: 1000 µg/L. (Perkin Elmer, USA). 2. Multi- element calibration standard (Ag, Al, As, Ba, Be, Bi, Ca, Cd, Co, Cr, Cs, Cu, Fe, Ga, Hg, In, K, Li, Mg, Mn, Na, Ni, Pb, Rb, Se, Sr, Tl, U, V, Zn). Matrix per volume: 5% HNO_3 per 100 ml. Concentration of elements: 200 µg/L. (Perkin Elmer, USA). 3) K, Na, Ca, Mg, Fe, Matrix per volume: 5% HNO_3 per 100 ml. Concentration of elements: 1000 µg/L. (Perkin Elmer, USA).

Honey Samples

Twenty one honey samples were collected directly from the beekeepers during 2005 - 2006 harvest from different locations in *Lawdar* region(Abyan Governorate, Yemen) and classified according to their botanical Origin to six kinds (see table 1). All honey samples were free from granulation, placed in plastic jars and kept at room temperature.

Samples Digestion

Samples were digested according to 920,180 method (A.O.A.C. 2000b). 12.5 ml of 75% HNO_3 and 1.5 ml of H_2O_2 were added to 5g of each honey sample within a Pyrex glass. The acid was evaporated on an electrically heated metal sheet at 100 - 120 ºC, and then the residue was transferred to a volumetric flask (25 ml) with distilled water. Blank digestion was also carried out in the same way, but in the absence a honey samples.

Analysis of Honey Samples

The analyzed metals (13 metals in each sample) were divided into two groups:

First group: Al, Mn, Co, Ni, Cd, Cu, Pb, and Hg (see Table 2), was determined by the Inductively Coupled Plasma-Mass Spectrometry (ICP-MS, Perkin Elmer model ELAN DRC II, U.S.A). The operating parameters for ICP-MS are indicating in Table 3.

Second group: Na, Ca, K, Mg, Fe and Al (see Table 4) were determined by Atomic Absorption Spectrometry (AAS, flame system model AAnalyst 800 PerkinElmer, USA). All the elements rates, that found in this study, were expressed by milligram or microgram per litter (mg/kg or µg/kg).

Statistical Analysis

Data were subjected to analysis of ANOVA, the least significant difference (LSD) at 5% probability and correlation using the Statistical Package for the Social Sciences (SPSS) Ver. 12, software for windows.

Results and Discussion

The analyzed thirteen minerals, for discussion, were divided into three groups: the major, heavy and toxic elements. The total mean content of the analyzed thirteen minerals were 2152.46 mg/kg in sider, 1950.16 mg/kg in Somarah, 1281.98 mg/kg in Sisban, 1134.93 mg/kg in Maraee. 982.90 mg/kg in Kasas and 774.23 mg/kg in Maeruah honeys.

1) The Major Elements: This group contains K, Ca, Na and Mg. The results in the table 5, showed that K and Ca were, quantitatively, the most abundant among the other studied elements in all samples, followed by Na and Mg. The highest concentration of K, which its concentration influenced by the botanical origin of honey, was observed in Sider and Somarah honey kinds. Wide range of K content was found, where 3118.85 mg/Kg was the highest value found in sample 3, while the lowest (112.62 mg/kg) was in sample 20. The above results were lower than that found by Golob *et al*., (2005), in *Slovenian* honey. Kaakeh and Gad EL-Hak, (2005), found that the range of K content was 273.5 - 5340.9 mg/l, and its range content in Sidir honey 1719.2 - 3007.2 mg/l, this corroborated our results. Also our results-mostly- in agreement with Fernandez *et al*., (2005), Torres *et al*., (2005), Saleh, (2005), Marcelo et al, 2007, Bağci et al, 2007, Saif-ur-Rehman, 2008 and EL-Fadaly *et al*., (1999), who determined the K content, and in some *Yemeni* honeys, Dhapa (621.0ppm), Samer (1608.0 ppm), and Merbeiy (1539.0 ppm). Abo-Tarboush *et al*., (1993), reported that the concentration of K in Sidir was higher than that found in other *Saudi* honey kinds. As we can see from the table 8 there was a positive correlation (P= 0.01) between: K and total element content (R= 0.955) and K and Mg content (R= 0.609).On the other hand there was a negative correlation (P= 0.01) between K and Ca content (R= - 0.535). The minimum concentration of Ca (116.755 mg/kg) seems in sample 1, while the maximum (890.950 mg/kg) was in sample 14. These results were in accordance with the results of Hassan and Abd El-Aal, (1997); Conti, (2000); Golob *et al*., (2005) and Lachman *et al.,* (2007) Marcelo et al, 2007, Bağci et al, 2007 and Saif-ur-Rehman, 2008. The results obtained by AL-Fadaly *et al.,* (1999), were disagreeing with our findings. The highest value of Na was (153.53 mg/kg) found in sample 10 and the lowest value was (16.89 mg/kg) in sample 1. These values were in agreement with Saleh, (2005), but lower than that found by Latorre *et al*., (1999); Conti, (2000), and Nafea and Tharwat, (2006) and Saif-ur-Rehman, 2008. The lowest concentration (11.96 mg/kg) of Mg was in sample 18 and the highest concentration (190.98 mg/kg) was in sample 3. Somarah honey has the highest content (96.96 mg/kg), while the lowest content was (43.33 mg/kg) in Maeruah honey. These values were higher than that observed by Uren *et al*., (1998); Rashed and Sultan, (2004), Downey *et al*., (2005) and Marcelo et al, 2007.

2) The Heavy metals: Fe, Al, Mn, Ni, Co and Cu all are the members of this group. Their data are shown in the table 6. The lowest content of Fe was (0.17 mg/kg) in sample 1 and the highest content was (14.21 mg/kg) in sample 14. The maximum mean value for Fe was in Sisban honey followed by Somarah, Maraee, Kasas, Sidir and Maeruah honeys respectively. In previous studies, Uren *et al*., (1993), reported that the range of Fe content was 4.90 - 19.7 ppm, and Rashed and Sultan, (2004), reported that the range of Fe content was 58 - 202 µg/g and Macelo et al, 2007, observed that the mean Fe content was 6.34 mg/kg. As illustrated in the table 6, the Al content in samples 6 and 12, which were collected from *Aleyenn* zone of Lawdar region, contrary to that of other samples, was quite very high. However, our results about Al content were lower than that reported by Lachman *et al*., (2007), and Fredes and Montenegro (2006), while, higher than results obtained by Al -Khalifa and Al - Arify, (1999). The concentration of Mn varied from the lowest of 0.041 mg/kg in sample 1 to the highest 0.424 mg/kg in sample 14. The high content of Mn was in Maeruah honey and the lowest in Sidir honey. The concentration of Mn in our study is in agreement with the results of Al -Khalifa and Al - Arify, (1999) and Marcelo et al, 2007, but disagree with the high Mn content found by Kucuk et al, (2007). The lowest concentration of Cu was 0.033 mg/kg, which was found in sample 10 and the highest 1.561 mg/kg in sample 7. In the studied honey kinds, the highest value was 0.62 mg/kg in Somarah and

the lowest value was 0.08 mg/Kg in Maraee honey. Our findings for the Cu content were lower than those reported by Caroli *et al*, (2000); Braziewicz *et al*., (2002); Atrouse *et al,* (2004), Terrab *et al*, (2005), Goloob *et al*, (2005), Downey *et al*, (2005) and Hernandez *et al*., (2005), However, the similar results were observed by Ioannidou *et al*, (2005), Staniskiene *et al*, (2006) Marcelo et al, 2007 and Saif-ur-Rehman, 2008. The Ni amount in the studied samples ranged from 040 mg/kg (sample 10) to 1.434 mg /kg (sample 20). The mean values for Ni content in the honey Kinds were 0.074; 0.079; 0.107; 0.116; 0.117; 0.524 mg/kg in Sidir, Kasas, Maeruah, Somarah, Sisban and Maraee honeys respectively. As we can see from our findings, the Ni content was lower than the results published by Matei *et al,* (2004); Rashed and Soltan, (2004); Golob *et al*, (2005) and Lachman *et al*, (2007). Mn and Ni have concentrations -mostly in all samples- ranged below 0.12 - 1,2 mg/kg and 0.2 - 2.5 mg/kg, the recommended daily intake in Romania for Mn and Ni respectively (Matei et al, 2004). Excluding sample 6 (118,92 mg/kg), all samples had a Co content varying from 0.380 µg /kg (sample 4) to 11.910 µg /kg (sample 3). However, our findings were less than that reported by Rashed and Sultan, (2005), on the other hand they were in agreement with the finding of Ioannodou *et al*., (2005), and Terrab *et al*., (2005).

3) Toxic elements: Air and water contain heavy metals from industry and traffic which can also contaminate the bee colony and its products. The air can contain lead and cadmium, while cadmium can also be transported via water and soil to the plants to reach the nectar and the honeydew [Bogdanov et al. 2003].

Table 7 gives values of the studied toxic elements (Pb, Cd and Hg).

The Pb content (both isotopes) in all samples varying from ~ 0.014 mg/kg (sample 9) to ~ 0.220 mg/kg (sample 2). On the other hands, the maximum mean value of Pb content was (0.079 mg/kg) in Sisban honey kind, while the minimum mean value was (0.040 mg/kg) found in Maraee honey kind. It was noticeable that the samples from *Emmagl* (2, 7, 11, and 21), *Lawdar* (13 and 15) and *Aleyenn* (6, 12 and 14) showed high levels of Pb. The reason might be that possibly apiaries are located at a distance not far from the polluted habitat in this area near the roads. However, the results in the present study are lower than those reported by Caroli *et al,* (2000); Bratu and Georgescu, (2005); Golob *et* al, (2005) and Munoz and Palmero, (2006).

Cd also is a toxic heavy metal and non essential for human health and the most important sources of pollution with it are metal industry, plastics and sewers [Demirezen and Aksoy 2005]. As we can see from the Table 7, Cd was not detected in most of the analyzed honey samples. It was detected only in 5 samples (7, 11, 13, 14, and 18). The highest values were 5.45 µg / Kg in sample 7 and 19.07 µg / Kg in sample11, while the Cd content in the other three samples was ranged from 1.45 (sample 14) to o.08 µg /kg (sample 13). The appearance of Cd in honeys was stated in some articles such as: Ioannidou *et al*, (2005), who reported that the range of Cd content in *Greece* honey was from 0.038 mg/kg to 0.222 mg/kg; Vinas *et al,* (1997), stated that the range of Cd content in *Spanish* honey was varied from not detected to 5.4 ng/g [Przybylowski 2001], in *Polish* honey found that the range of Cd is 0.025 - 0.07mg/kg and Rashed and Soltan, (2004), reported that the range of Cd in *Egyptian* honey varied from 0.01 - 0.50 µg/g (DW).

In *European* legislation, the maximum allowable content of Pb and Cd in honey is 1.0 and 0.5 mg/kg respectively [Bogdanov et al. 2003]. All the values of Pb and Cd were in this investigation lower than the above legislation.

Hg, which was detected only in seven samples (1, 10, 11, 14, 16, 17 and 18), have concentrations ranged too much below 0.5 mg/kg, the certified value for Hg in the Italian honey [Vorlova and Celechovska 2000]. Our findings were also much lower that the finding of Khan et al, 2005, who found that the Hg content in Pakistan honey ranged from 0.05 to 1.35 mg/kg. On the other hand our results were higher than the findings of Celechovska and Vorlova, 2001, and Vorlova and Celechovska, 2000, which are 0.67-2.93 and 1.05-1.91 µg/kg respectively in the Czech honeys.

Statistical analysis

Means in a column (Tables 5-7) not sharing the same superscript are significantly different at $p<0.05$. Data presented in Table 8 show that significant correlations were observed between the mineral elements of the studied honeys.

Conclusion

1. The concentration of K in Sider and Somarah honey samples was higher than other honey kinds, and both honey Kinds (Sider and Somarah) are good source for it.

2. Lawadar honey samples were not free of the toxic metals, but their concentrations were well below the permitted levels and do not pose any serious concern to human health.

3. The high variation of the trace element levels, observed in the studied honey samples, is likely due to the different impact of common anthropogenic pollution sources (e.g. traffic, coal/wood combustion and water) in the vicinity of the gathering areas, where the beehives were placed.

4. The variation between our and previous studies may be due to: a) the different sources (plant sources) of honeys, b) the different methods of extracting, of honey from the hives and methods, and analysis.

Table 1. *Shows Location and Names of Studied Honey Kinds*

Type of Honey			Location	Serial No
Scientific Name	Common Name	Arabic Name		
*Ziziphus spina-christs (*l)	Sidir	Ailb	*DAMAN*	1
			EMMAGL	2
			ALROQOB	3
			AL-GOF	4
			ALHADN	5
Acacia	Somarah	Sumar	*ALEYENN*	6
			EMMAGL	7
			ALHADN	8
Euphorbia Inarticulate schweinf	Kasas	Sal	*ALSORAH*	9
			ALHADN	10
			EMMAGL	11
			ALEYENN	12
Proso pis juliflora	Sisban	Moskeet	*LOWDER*	13
			ALEYENN	14
			LOWDER	15
Maerua crassfolia forssk	Maerua	Maeruah	*ALHADN*	16
			ALROQOB	17
			QUATH	18
Multifloral	Maraee	Maraee	*ALHADN*	19
			ALROQOB	20
			EMMAGL	21

Table 2. *Elements Which Analysed by ICP-MS*

Analyte	Al	Mn	Co	Ni	Cu		Cd	Hg		Pb	
Mass	27	55	59	60	63	65	113	201	202	207	208
Detection limits p.p.t	0.1 - 10										

Table 3. *Operating parameters for ICP – MS*

Plasma Power	1200 Watt
Plasma Gas Flow Rate	Ar 15.0 L/Min
Auxiliary Gas Flow Rate	Ar 1.20 L/Min
Neeblizer Gas Flow Rate	Ar 0.9 L/Min
Plasma Temperature	5000 - 7000 ^{o}C

Table 4. *The Wavelength and Detection Limits of Elements Which Analyzed by AAS*

Analyte	Wave Length λ (nm)	Lamp	Detection Limits ppb
Na	330.2	HCL	0.3
K	404.4		0.3
Ca	422.7		1.5
Mg	285.2		0.15
Fe	248.3		5.0

Table 5. *The Content of K, Ca, Na, and Mg in Honey Samples*

Kinds of Honey	No of Sample	K (mg/Kg)			Ca (mg/Kg)			Na (mg/Kg)			Mg (mg/Kg)		
		Mean	SD	RSD%	Mean	SD	RSD%	Mean	SD	RSD%	Mean	SD	RSD%
Ziziphus spina-christs (Sidir)	1	988.60	14.70	1.49	116.76	4.75	4.07	16.89	0.35	2.07	22.93	0.51	2.22
	2	2081.20	18.16	0.87	191.88	0.84	0.44	84.92	1.92	2.26	42.60	0.22	0.52
	3	3118.85	22.03	0.71	265.25	1.12	0.42	47.31	0.88	1.86	190.98	1.29	0.68
	4	1639.65	77.42	4.72	179.26	0.54	0.30	83.84	5.79	6.91	34.83	2.31	6.63
	5	1321.85	15.53	1.17	147.66	4.51	3.05	34.60	12.10	34.97	35.03	3.17	9.05
Mean		1830.03 [a]			180.16 [b]			53.51 [a]			65.27 [a]		
Acacia (Somarah)	6	1358.90	25.24	1.86	281.64	3.42	1.21	81.57	13.84	16.97	100.90	8.83	8.75
	7	1707.50	15.39	0.90	407.41	1.30	0.32	93.44	1.38	1.48	139.10	1.28	0.92
	8	1074.40	134.66	12.53	295.26	2.18	0.74	37.79	7.15	18.92	50.89	4.30	8.45
Mean		1380.27 [a]			328.10 [ab]			70.93 [a]			96.96 [a]		
Euphorbia inarticulate schweinf (Kasas)	9	520.50	10.25	1.97	450.47	8.00	1.78	42.00	1.72	4.10	46.23	0.47	1.02
	10	198.96	2.62	1.32	405.54	8.96	2.21	153.53	3.19	2.08	69.93	1.31	1.87
	11	421.43	9.06	2.15	291.59	21.71	7.45	42.09	3.90	9.27	32.96	0.66	2.00
	12	490.83	21.06	4.29	466.74	6.14	1.32	119.85	2.74	2.29	72.32	0.40	0.55
Mean		407.93 [b]			403.59 [a]			89.37 [a]			55.36 [a]		
Prosopis juliflora (Sisban)	13	825.20	35.36	4.29	403.80	1.80	0.45	109.06	3.46	3.17	38.11	0.02	0.05
	14	225.14	4.28	1.90	890.95	22.55	2.53	115.96	5.02	4.33	74.86	6.03	8.06
	15	610.25	40.42	6.62	350.68	32.05	9.14	63.25	0.64	1.01	34.54	0.36	1.04
Mean		553.53 [b]			548.48 [a]			96.09 [a]			49.17 [a]		
Maerua crassfolia forssk (Maeruah)	16	150.66	7.68	5.10	518.40	6.89	1.33	121.25	1.59	1.31	47.13	1.38	2.93
	17	160.66	7.84	4.88	590.60	16.81	2.85	135.65	3.00	2.21	70.90	2.84	4.01
	18	161.59	17.20	10.64	243.44	20.90	8.59	19.13	0.78	4.07	11.96	1.30	10.87
Mean		157.64 [b]			450.81 [a]			92.01 [a]			43.33 [a]		
multifloral (Maraee)	19	453.85	5.22	1.15	457.04	8.77	1.92	117.66	0.79	0.67	44.18	0.33	0.75
	21	112.62	1.09	0.97	495.21	10.73	2.17	51.92	4.00	7.70	29.34	0.58	1.98
	21	693.20	4.74	0.68	483.49	11.52	2.38	68.83	2.02	2.93	59.41	0.02	0.03
Mean		419.89 [b]			478.58 [a]			79.47 [a]			44.31 [a]		

Any two means within a column having the same letters are not significant difference at ($p < 0.05$).

Table 6. *The Content of Fe, Al, Mn, and Ni in Honey Samples*

Kinds of Honey	No of Sample	Fe (mg/Kg)			Al (mg/Kg)			Mn (mg/Kg)			Ni (mg/Kg)		
		Mean	SD	RSD%	Mean	SD	RSD%	Mean	SD	RSD%	Mean	SD	RSD%
Ziziphus spinachrists (Sidir)	1	0.170	0.112	65.882	0.473	0.004	0.846	0.0414	0.0006	1.449	0.0469	0.0005	1.066
	2	1.330	0.007	0.526	1.276	0.020	1.567	0.0598	0.0010	1.672	0.0686	0.0010	1.458
	3	3.775	0.238	6.305	1.723	0.047	2.727	0.1797	0.0027	1.503	0.1692	0.0025	1.478
	4	1.700	0.019	1.118	2.816	0.067	2.379	0.2077	0.0049	2.359	0.0551	0.0015	2.722
	5	0.730	0.029	3.973	0.834	0.001	0.120	0.0445	0.0003	0.674	0.0321	0.0010	3.115
Mean		1.541 [a]			1.424 [a]			0.1066 [df]			0.0744 [a]		
Acacia (Somarah)	6	2.085	0.067	3.213	11.882	0.179	1.506	0.1657	0.0022	1.328	0.1598	0.0015	0.939
	7	2.615	0.085	3.250	1.033	0.022	2.130	0.1149	0.0017	1.480	0.1292	0.0005	0.387
	8	1.930	0.071	3.679	2.308	0.016	0.693	0.1802	0.0010	0.555	0.0598	0.0005	0.836
Mean		2.210 [a]			5.074 [a]			0.1536 [ad]			0.1163 [a]		
Euphorbia inarticulate schweinf (Kasas)	9	2.340	0.288	12.308	1.728	0.005	0.289	0.2029	0.0020	0.986	0.0590	0.0008	1.356
	10	0.720	0.056	7.778	0.868	0.031	3.571	0.1449	0.0072	4.969	0.0401	0.0018	4.40
	11	2.095	0.147	7.017	2.111	0.113	5.353	0.1824	0.0066	3.618	0.0559	0.0033	5.903
	12	1.575	0.013	0.825	19.194	0.027	0.141	0.1984	0.0011	0.554	0.0825	0.0015	1.818
Mean		1.683 [a]			5.975 [a]			0.1822 [ad]			0.0594 [a]		
Prosopis juliflora (Sisban)	13	1.935	0.058	2.997	2.336	0.020	0.856	0.1792	0.0012	0.670	0.1188	0.0020	1.684
	14	14.201	0.033	0.232	3.830	0.008	0.209	0.4242	0.0036	0.849	0.1709	0.0023	1.346
	15	1.310	0.081	6.183	1.512	0.003	0.198	0.1586	0.0011	0.694	0.0618	0.0010	1.618
Mean		5.816[a]			2.559 [a]			0.2540 [ac]			0.1172 [a]		
Maerua crassfolia forssk (Maeruah)	16	1.510	0.122	8.079	2.490	0.031	1.245	0.2197	0.0036	1.639	0.0983	0.0020	2.035
	17	1.290	0.081	6.279	0.852	0.035	4.108	0.3958	0.0009	0.227	0.0669	0.0005	0.747
	18	1.680	0.139	8.274	3.344	0.018	0.538	0.1500	0.0006	0.40	0.1573	0.0020	1.272
Mean		1.493 [a]			2.229 [a]			0.2552 [ab]			0.1075 [a]		
Multifloral (Maraee)	19	2.485	0.113	4.547	2.529	0.014	0.554	0.1608	0.0022	1.368	0.0806	0.0003	0.372
	20	2.110	0.084	3.981	1.636	0.025	1.528	0.1876	0.0042	2.239	1.4335	0.0405	2.825
	21	1.115	0.044	3.946	1.104	0.014	1.268	0.0779	0.0015	1.926	0.0590	0.0008	1.356
Mean		1.903 [a]			1.756 [a]			0.1421 [ad]			0.5244 [a]		

Any two means within a column having the same letters are not significant difference at ($p < 0.05$).

Table 6. *Continued: The Content of Co and Cu in Honey Samples*

Kinds of Honey	No of Sample	Co (µg/Kg)			Cu 63 (mg/Kg)			Cu 65 (mg/Kg)		
		Mean	SD	RSD%	Mean	SD	RSD%	Mean	SD	RSD%
Ziziphus spinachrists (Sidir)	1	0.660	0.010	5.200	0.0678	0.0012	1.6962	0.0700	0.0018	2.5000
	2	8.385	0.020	1.200	0.1037	0.0002	0.1929	0.1025	0.0022	2.1462
	3	11.910	0.040	1.500	0.2307	0.0019	0.8237	0.2268	0.0024	1.0582
	4	0.380	0.011	2.900	0.0770	0.0013	1.6892	0.0750	0.0020	2.5986
	5	5.465	0.011	0.200	0.0638	0.0002	0.3134	0.0625	0.0002	0.3198
Mean		5.360 [a]			0.1086 [b]			0.1065 [b]		
Acacia (Somarah)	6	118.920	0.110	0.400	0.1810	0.0018	0.9666	0.1770	0.0020	1.1019
	7	1.750	0.016	0.900	1.5377	0.0228	1.4827	1.5837	0.0301	1.9007
	8	1.570	0.014	1.400	0.1116	0.0005	0.4031	0.1092	0.0009	0.7786
Mean		40.747 [a]			0.6101 [a]			0.6233 [a]		
Euphorbia inarticulate schweinf (Kasas)	9	2.395	0.010	2.400	0.0496	0.0004	0.8057	0.0477	0.0003	0.5243
	10	1.910	0.008	0.400	0.0348	0.0022	6.1720	0.0321	0.0017	5.3042
	11	2.765	0.010	1.100	0.1335	0.0055	4.0819	0.1290	0.0046	3.5264
	12	0.665	0.000	2.100	0.1123	0.0002	0.1336	0.1103	0.0003	0.2267
Mean		1.934 [a]			0.0826 [b]			0.0798 [b]		
Prosopis juliflora (Sisban)	13	2.165	0.020	3.800	0.0849	0.0005	0.5298	0.0827	0.0004	0.4233
	14	1.655	0.010	2.100	0.1618	0.0016	0.9890	0.1580	0.0017	1.0761
	15	2.090	0.010	1.500	0.0559	0.0008	1.4311	0.0545	0.0009	1.5593
Mean		1.970 [a]			0.1009 [ab]			0.0984 [ab]		
Maerua crassfolia forssk (Maeruah)	16	1.300	0.000	1.900	0.1294	0.0017	1.2751	0.1241	0.0024	1.9332
	17	10.315	0.010	0.600	0.0433	0.0004	0.9245	0.0409	0.0003	0.7330
	18	2.250	0.010	1.500	0.0844	0.0004	0.4148	0.0822	0.0002	0.1824
Mean		13.865 [a]			0.0857 [b]			0.0824 [b]		
Multifloral (Maraee)	19	2.875	0.010	0.900	0.0716	0.0013	1.7465	0.0688	0.0010	1.3808
	20	1.000	0.000	0.500	0.1119	0.0033	2.9041	0.1077	0.0030	2.7391
	21	7.810	0.030	1.700	0.0581	0.0014	2.4086	0.0555	0.0015	2.6119
Mean		3.895 [a]			0.0805 [b]			0.0773 [b]		

Any two means within a column having the same letters are not significant difference at ($p < 0.05$).

Table 7. *The Content of Pb, Hg and Cd in Honey Samples*

Kinds of Honey	No of Sam-ple	Pb 207 (mg/kg)		Pb 208 (mg/kg)		Hg 201 (µg/kg)		Hg 202 (µg/kg)		Cd (µg/kg)	
		Mean	RSD%	Mean	RSD%	Mean	RSD%	Mean	RSD%	Mean	RSD%
Ziziphus spinachrists (Sidir)	1	0.0509	0.982	0.0504	1.40	2.74	1.095	2.64	1.136	ND	ND
	2	0.2232	1.434	0.2168	1.1061	ND	ND	ND	ND	ND	ND
	3	0.0467	1.071	0.0450	1.111	ND	ND	ND	ND	ND	ND
	4	0.0427	2.576	0.0415	2.892	ND	ND	ND	ND	ND	ND
	5	0.0149	1.342	0.0148	1.351	ND	ND	ND	ND	ND	ND
Mean		0.0757 ^{a}		0.0737^{a}		0.49 ^{b}		0.53 ^{b}		nd	
Acacia (Somarah)	6	0.0791	0.379	0.0783	1.149	ND	ND	ND	ND	ND	ND
	7	0.0509	2.554	0.0493	2.637	ND	ND	ND	ND	5.45	1.835
	8	0.0324	0.309	0.0313	0.959	ND	ND	ND	ND	ND	ND
Mean		0.0541 ^{a}		0.0530^{a}		ND		ND		1.82 ^{a}	
Euphorbia inarticulate schweinf (Kasas)	9	0.0142	0.704	0.0141	0.709	ND	ND	ND	ND	ND	ND
	10	0.0150	8.0	0.0147	7.483	2.16	6.944	2.09	6.220	ND	ND
	11	0.1605	3.240	0.1579	3.293	4.58	1.965	4.50	1.778	19.05	2.625
	12	0.0961	1.041	0.0928	0.647	ND	ND	ND	ND	ND	ND
Mean		0.0714 ^{a}		0.0699^{a}		1.44 ^{b}		1.65 ^{b}		4.76 ^{a}	
Prosopis juliflora (Sisban)	13	0.1005	0.398	0.0977	0.818	ND	ND	ND	ND	0.075	102.67
	14	0.0818	1.467	0.0798	1.629	3.25	0.615	3.43	1.166	1.45	3.448
	15	0.0555	1.441	0.0542	2.030	ND	ND	ND	ND	ND	ND
Mean		0.0793 ^{a}		0.0773^{a}		1.08 ^{b}		1.14 ^{b}		0.51 ^{a}	
Maerua crassfolia forssk (Maeruah)	16	0.0651	1.833	0.0644	1.863	15.12	0.794	15.03	0.998	ND	ND
	17	0.0433	4.388	0.0429	3.497	5.84	1.027	5.74	1.220	ND	ND
	18	0.0315	3.175	0.0304	3.300	1.97	2.538	1.78	2.810	0.63	15.873
Mean		0.0466 ^{a}		0.0459^{a}		7.64 ^{a}		7.51 ^{a}		0.21 ^{a}	
Multifloral (Maraee)	19	0.0364	1.923	0.0353	1.416	ND	ND	ND	ND	ND	ND
	20	0.0357	2.521	0.0347	3.746	ND	ND	ND	ND	ND	ND
	21	0.0482	1.867	0.0474	2.532	ND	ND	ND	ND	ND	ND
Mean		0.0401 ^{a}				ND		ND		ND	

Any two means within a column having the same letters are not significant difference at ($p < 0.05$).
ND= not detected.

Table 8. *Pearson Correlations Among Honey Samples Factors*

Elements	K	Ca	Na	Mg	Fe	Al	Cu	Mn	Pb	Co	Ni	Hg	Cd	total
Ca Pearson Correlation Sig. (2-tailed)	- .535** .012	1	.583** .006	.140 .544	.677** .001	.106 .646	.048 .836	.765** .000	- .085 .741	- .131 .571	.197 .393	.298 .190	- .054 .815	-.275 .228
Na Pearson Correlation Sig. (2-tailed)	-.260 .254	.583 .006	1	.206 .369	.194 .399	.228 .320	.070 .763	.466* .033	.101 .663	.020 .932	- .138 .549	.291 .201	- .171 .459	-.079 .734
Mg Pearson Correlation Sig. (2-tailed)	.609** .003	.140 .544	.206 .369	1	.250 .275	.147 .525	.527* .014	.143 .536	- .061 .792	.288 .295	- .084 .718	- .124 .593	- .023 .922	.764** .000
Fe Pearson Correlation Sig. (2-tailed)	.073 .754	.677** .001	.194 .399	.250 .275	1	.059 .801	.094 .686	.644** .002	.086 .710	- .027 .907	.068 .768	.044 .851	.059 .800	.122 .597
Al Pearson Correlation	-.068 .770	.106 .646	.228 .320	.147 .525	.059 .801	1	- .059 .799	.137 .555	.181 .432	.424 .056	- .040 .864	- .121 .601	- .081 .728	-.008 .972

Sig. (2-tailed)														
Cu Pearson Correlation Sig. (2-tailed)	.316 .163	.048 .836	.070 .763	.527* .014	.094 .686	-.059 .799	1	-.113 .627	-.007 .976	-.001 .996	.009 .968	-.097 .676	.251 .273	.388 .082
Mn Pearson Correlation Sig. (2-tailed)	-.373 .095	.765** .000	.466* .033	.143 .536	.644** .002	.137 .555	-.113 .627	1	-.068 .771	-.020 .932	.083 .721	.348 .122	.018 .937	-.170 .461
Pb Pearson Correlation Sig. (2-tailed)	.208 .365	-.085 .714	.101 .663	-.061 .792	.086 .710	.181 .432	-.007 .976	-.068 .771	1	.094 .686	-.110 .634	.062 .789	.421 .058	.203 .377
Co Pearson Correlation Sig. (2-tailed)	.205 .373	-.131 .571	.020 .932	.288 .205	-.027 .907	.424 .056	-.001 .996	-.020 .932	.094 .686	1	-.014 .952	-.118 .611	-.080 .730	.242 .290
Ni Pearson Correlation Sig. (2-tailed)	-.189 .412	.197 .393	-.138 .549	-.084 .718	.068 .768	-.040 .864	.009 .968	.083 .721	-.110 .634	-.014 .952	1	-.106 .648	-.077 .739	-.086 .710
Hg Pearson Correlation Sig. (2-tailed)	-.397 .075	.298 .190	.291 .201	-.124 .593	.044 .851	-.121 .601	-.097 .676	.348 .122	.062 .789	-.118 .611	-.106 .648	1	.160 .490	-.357 .112
Cd Pearson Correlation Sig. (2-tailed)	-.082 .723	-.054 .815	-.171 .459	-.023 .922	.059 .800	-.081 .728	.251 .273	.018 .937	.421 .058	-.080 .730	-.077 .739	.160 .490	1	-.116 .617
Total Pearson Correlation Sig. (2-tailed)	.955** .000	-.275 .228	-.079 .734	.764** .000	.122 .597	-.008 .972	.388 .082	-.170 .461	.203 .377	.242 .290	-.086 .710	-.357 .112	-.116 .617	1

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

Bibliography

1. **Abo-Tarboush, H. M., K. I. M. AL-Malah and M. S. EL-Sarrage (1993).** Floral-Type Identification and Quality Evaluation of Some Honey Types // Food Chemistry. - № 46. – Pp. 13-17.
2. **AL-Khalifa A. S. and I. A. AL-Arify (1999).** Physicochemical Characteristics and Pollen Spectrum of Some Saudi Honeys // Food Chemistry. - № 67 (1). – Pp. 21-25.
3. **Anklam Elke (1998).** A Review of the Analytical Methods to Determine the Geographical and Botanical Origin of Honey // Food Chemistry. - № 63 (4). – Pp. 549-562.
4. **Atrouse Omar M., Sawsan A. Oran and Soud Y. Al-Abbadi (2004).** Chemical Analysis and Identification of Pollen Grains from Different Jordanian Honey Samples // International Journal of Food Science and Technology. - № 39. – Pp. 413-417.
5. **Bağci Yavuz, Arslan Derya, Özcan M. Musa, Dursun Nesim (December 2007).** Determination of Mineral Contents of Bee Honeys Produced in Middle Anatolia // International Journal of Food Sciences and Nutrition. - № 58 (8). - Pp. 668-676
6. **Bogdanov S., Anton Imdrof., Jean-Daniel Charriere, Peter Fluri and Verena Kilchenmann (2003).** The Contaminations of the Bee Colony // Swiss Bee Research Centre. – Pp. 1-12.
7. **Bratu Luliana and Georgescu Cecilia (2005).** Chemical Contamination of Bee Honey - Identifying Sensor of the Environment Pollution // Central European Agriculture. - № 6 (1). – Pp. 467-470.

8. Braziewicz J., I. Fijał, T. Czyzewski, M. Jaskoła, A. Korman, D. Banas, A. Kubala-Kuku and U. Majewska, L. Zemło (2002). PIXE and XRF Analysis of Honey Samples // Nuclear Instruments and Methods in Physics Research. - № B 187. – Pp. 231-237.

9. Caroli S., G. Forte, M. Alessandrelli, R. Cresti, M. Spagnoli, S. Dilio, J. Pauwels and G. N. Kramer (2000). A Pilot Study for the Production of a Certified Reference Material for Trace Elements in Honey // Microchemical Journal. – № 67. – Pp. 227-233.

10. Celechovska O. and L. Vorlova (2001). Groups of Honey - Physicochemical Properties and Heavy Metals // Acta Vet. Brno. - № 70. - P. 91-95.

11. Conti Marcelo Enrique (2000). Lazio Region (Central Italy) Honeys: A Survey of Mineral Content and Typical Quality Parameters // Food Control. - № 11. – Pp. 459-463.

12. Demirezen Dilek and Ahmet Aksoy (2005). Determination of Heavy Metals in Honey Bee Using by Inductively Coupled Plasma Optical Emission Spectroscopy (ICP_OES) // G. U. Journal of Science. - № 18 (4). – Pp. 569-575.

13. Downey Gerard, Karen Hussey, J. Daniel Kelly, Thomas F. Walshe and P. G. Martin (2005). Preliminary Contribution to the Characterizations of Artisanal Honey Produced On the Island of Ireland by Palynological and Physico-Chemical Data // Food Chemistry. - № 91. – Pp. 347-354.

14. EL-Fadaly H., F. S. Abdilla and E. E. Y. EL-Badrawy (1999). Comparative Study between Yemeni and Egyptian Types of Honey by Means of Antibacterial Activity // Pakistan Journal of Biological Sciences. - № 2 (1). – Pp. 1-6.

15. Fernandez-Torres Rut, Juan Luis Perez-Bernal, Miguel Angel Bello-Lopez, Manuel Callejon-Mochon, Juan Carlos Jimenez-Sanchez and A. Guiraum-Perez (2005). Mineral Content and Botanical Origin of Spanish Honeys // Talanta. - № 65. – Pp. 686-691.

16. Fredes C. and G. Montenegro (2006). Heavy Metals and Other Trace Elements Contents in Chilean Honey // Ciencia E investegacion Agraria. - № 33 (1). - Pp. 50-58.

17. Golob T., U. Dobersek, P. Kump and M. Necemer (2005). Determination of Trace and Minor Elements in Slovenian Honey by Total Reflection X-Ray Fluorescence Spectroscopy // Food Chemistry. - № 91. – Pp. 593-600.

18. Hassan A. R. and H. A. Abd EL-Aal (1997). Physicochemical Analysis of Some Honey Types in Egypt. Sugar and Sugar Substitutes in Food Processing and Nutrition. - October 14th - 16th. - Suez Canal University.

19. Hernandez O. M., J. M. G. Fraga., A. I. Jimenez, F. Jimenez and J. J. Arias (2005). Characterization of Honey from the Canary Islands: Determination of the Mineral Content by Atomic Absorption Spectrophotometry // Food Chemistry. - № 93. – Pp. 449-458.

20. Ioannidou M. D., G. A. Zachariadis, A. N. Anthemidis and J. A. Stratis (2005). Direct Determination of Toxic Trace Metals in Honey and Sugars Using Inductively Coupled Plasma Atomic Emission Spectrometry // Talanta. - № 65. – Pp. 92-97.

21. Kaakeh Walid and Gad EL-Hak G. (2005). Sensory Evaluation and Chemical Analysis of *Apis Mellifera* Honey from the Arab Gulf Region // Journal of Food and Drug Analysis. - № 13 (4). – Pp. 331-337.

22. Khan M., Nasiruddin M. Qaiser, Syed Mubashir Raza and Mutiur Rehman (2005). Physicochemical Properties and Pollen Spectrum of Imported and Local Samples of Blossom Honey from the Pakistani Market // International Journal of Food Science and Technology. - № 40. – Pp. 1-8.

23. Kucuk Murat, Sevgi Kolayl, Sengu Karaoglu, Esra Ulusoy, Cemalettin Baltac and Ferda Candan (2007). Biological Activities and Chemical Composition of Three Honeys of Different Types from Anatolia // Food Chemistry. - № 100. – Pp. 526-534.

24. Marcelo Enrique Conti, Jorge Stripeikis, Luigi Campanella, Domenico Cucina and Mabel Beatriz Tudino (2007). Characterization of Italian Honeys (Marche Region) on the Basis of Their Mineral Content and Some Typical Quality Parameters // Chem. Central Journal. - № 1 (14). - Pp. 3-10.

25. Lachman J., D. Kolihova, D. Miholova, J. Kosata, D. Titera and K. Kult (2007). Analysis of Minority Honey Components: Possible Use for the Evaluation of Honey Quality // Food Chemistry. - № 101. – Pp. 973-979.

26. Matei Nicoleta, Semaghiul Birghila, Simona Dobrinas and Petre Capota (2004). Determination of C Vitamin and Some Essential Trace Elements (Ni, Mn, Fe, and Cr) in Bee Products // Acta Chim. Slov. - № 51. – Pp. 169-175.

27. Munoz Emma and Susana Palmero (2006). Determination of Heavy Metals in Honey by Potentiometric Stripping Analysis and Using a Continuous Flow Methodology // Food Chemistry. - № 94. – Pp. 478-483.

28. Nafea E. A. and E. A. Tharwat (2005). Minerals and Enzymes Composition of Honey of Different Botanical Origin in Saudi Arabia // Journal of Agricultural Sciences, Mansoura University. - № 30 (12). – Pp. 8217-8221.

29. Przybylowski Piotr and Aleksandra Wilczynska (2001). Honey as an Environmental Marker // Food Chemistry. - № 74. – Pp. 289-291.

30. Rashed M. N. and M. E. Soltan (2004). Major and Trace Elements in Different Types of Egyptian Mono-Floral and Non-Floral Bee Honeys // Journal of Food Composition and Analysis. - № 17. – Pp. 725-735.

31. Saif-ur-Rehman, Zia Farooq Khan and Tahir Maqbool (2008). Physical and Spectroscopic Characterization of Pakistani Honey // Cien. Inv. Agr. - № 35 (2). - Pp. 99-204.

32. Saleh A. S. Moussa (2005). Physico-Chemical and Technological Studies on Some Types of Egyptian Honey: Master Thesis in Agricultural Science. - Assiut University.

33. Staniskiene Birute, Paulius Matusevicius and Ruta Budreckiene (2006). Honey as an Indicator of Environmental Pollution // Environmental Research Engineering and Management. - № 36 (2). – Pp. 53-58.

34. Terrab Anass, Angeles F. Recamales, M. Lourdes Gonzalez-Miret and Francisco J. Heredia (2005). Contribution to the Study of Avocado Honeys by their Mineral Contents Using Inductively Coupled Plasma Optical Emission Spectrometry // Food Chemistry. - № 92. – Pp. 305-309.

35. Torres Rut, Fernandez Juan Luis Perez-Bernal, Miguel Angel Bello-Lopez, Manuel Callejon-Mochon, Juan Carlos Jimenez-Sanchez and A. Guiraum-Perez (2005). Mineral Content and Botanical Origin of Spanish Honeys // Talanta. - № 65. – Pp. 686-691.

36. Ueren A., A. Se Erifogae Lub and Y. Sarokahyac (1998). Distribution of Elements in Honeys and Effect of a Thermoelectric Power Plant on the Element Contents // Food Chemistry. - № 61 (1/2). - Pp. 185-190.

37. Vinas Pilar, Ignacio Lopez, Marcos Lanzen and Manual Hernandez-Cardoba (1997). Direct Determination of Lead, Cadmium and Copper in Honey by Elctothermal Atomic Absorption Spectrometry Using Hydrogen Peroxids As Matrix Modifier // Journal of Agricultural and Food Chemistry. - № 45. – Pp. 3952-3956.

38. Vorlova L. and O. Celehovska (2002). Activity of Enzymes and Trace Element Content in Bee Honey // Acta Vet. Brno. - № 71. – Pp. 375-378.

ДОЛИННАЯ ОРИЕНТАЦИЯ НЕРАВНОВЕСНЫХ НОСИТЕЛЕЙ ЗАРЯДА В КРИСТАЛЛАХ ПРИ ОДНО- И ДВУХФОТОННОМ ВОЗБУЖДЕНИИ

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Введение

Двухфотонное поглощение (ДФП) в кристаллах обычно изучается по возбуждаемой при ДФП люминесценции и фотопроводимости [Бонч-Бруевич 1965: 3; Бредихин 1973: 4; Коваленко В. Ф. 2003: 7]. С другой стороны, сами явления люминесценции и фотопроводимости часто удобнее исследовать при двухфотонном возбуждении, чем при однофотонном, из-за более однородного по объему характера возбуждения среды при ДФП. Особый интерес представляют исследования люминесценции и фотопроводимости в кристаллах кубической симметрии с многодолинным энергетическим спектром (халькогениды свинца, кремния, германия и др.). Дело в том, что в этих материалах из-за различия продольной и поперечной эффективных масс носителей заряда возбуждение электронно-дырочных пар в различные энергетические долины при ДФП сильно зависит от направления линейной поляризации излучения накачки относительно осей симметрии кристалла (при однофотонной накачке также имеется поляризационная зависимость, но более слабая). Таким образом, если время междолинного рассеяния неравновесных носителей больше времени жизни носителей относительно межзонной рекомбинации, то возможно осуществление селективного заполнения долин или так называемой долинной ориентации носителей. При этом рекомбинационное излучение (РИ) должно быть частично линейно поляризованным. По степени линейной поляризации РИ может быть определено отношение упомянутых времен, а при их отношении, много большем единицы, может быть определена степень анизотропии эффективных масс в энергетических долинах. При достаточно интенсивных накачках, когда РИ становится стимулированным (СРИ), селективное заполнение долин проявляется особенно ярко: при изменении направления линейной поляризации накачки имеет место периодическая модуляция интенсивности и степени поляризации СРИ, причем максимальная степень поляризации стимулированного РИ значительно выше, чем для спонтанного.

Селективное заполнение энергетических долин (долинная ориентация неравновесных носителей) наблюдалось в кристаллах PbTe при однофотонном возбуждении линейно поляризованным светом по частичной поляризованности спонтанного РИ [Lavallard 1975: 12], при двухфотонном возбуждении в PbTe [Арешев 1975: 1, Арешев 1976: 2] и PbSe [Данишевский 1982: 5] по сильной модуляции интенсивности и степени поляризации СРИ при изменении направления линейной поляризации накачки. При непрямом однофотонном возбуждении в Si это явление было обнаружено при исследовании циклотронного резонанса [Kaplyanskii 1976: 11]. В принципе долинная ориентация может быть обнаружена также и при измерении анизотропии фотопроводимости [Genzow 1978: 9].

Как уже было отмечено, необходимыми условиями селективного заполнения энергетических долин в кристаллах кубической симметрии с многодолинным энергетическим спектром при оптической накачке являются 1) различие продольной $m_{//}$ и поперечной $m_{\perp}$ эффективных масс носителей в долинах и 2) выполнение условия $\tau_r < \tau_{ss'}$, где τ_r − время жизни неравновесных носителей относительно межзонной рекомбинации, $\tau_{ss'}$ - время междолинного рассеяния неравновесных носителей. При достаточно низких температурах второе условие часто оказывается выполненным [Арешев 1975: 1; Арешев 1976: 2; Данишевский 1982: 5; Kaplyanskii 1976: 11; Lavallard 1975: 12].

Степень селективности заполнения энергетических долин зависит также от характера возбуждения (одно- и двухфотонное) и от направления вектора поляризации линейно поляризованного света накачки относительно кубических осей кристалла. В случае линейной спонтанной рекомбинации по степени поляризации РИ может быть определено отношение $\tau_r / \tau_{ss'}$. Соответствующий расчет будет проведен на примере кристаллов халькогенидов свинца.

Результаты расчета и обсуждение

Халькогениды свинца принадлежат к классу полупроводниковых соединений A_4B_6 и кристаллизуются в кубической решетке типа NaCl, точечная группа симметрии O_h. Валентная зона и зона проводимости в них описываются многоэллипсоидной моделью, причем эллипсоиды вытянуты в направлениях [111] (точка L зоны Бриллюэна) (Рис. 1).