Dependences of Ratio of the Luminosity to Ionization on Velocity and Chemical Composition of Meteors

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Abstract On the bases of results simultaneous photographic and radio echo observations, the results complex radar and television observations of meteors and also results of laboratory modeling of processes of a luminescence and ionization, correlation between of luminous intensity I_p to linear electronic density q from of velocities and chemical structure are investigated. It is received that by increasing value of velocities of meteors and decrease of nuclear weight of substance of particles, lg I_p / q decreased more than one order.

Keywords meteors · meteor luminosity · ionization

1 Introduction

Studying the interaction of processes of luminescence and ionization and investigating their dependence on the velocity of meteors belongs to the actual questions of meteor physics. Knowledge of these dependences need to address such important and yet unresolved until the end of questions, as a refinement of the scale radio magnitudes, as well as the mass scale as the photo and radar meteors. Attempts to study the interaction of processes of luminescence and ionization of meteors, as well as finding the dependence of the ratio coefficient of luminous to the ionization on the velocity in the range 32 < V < 62 km /s were made earlier than on the basis of data parallel visual-radar (Greenhow and Hawkins 1952), as well as photographic and radar observations (Davies and Hall 1963; Babadjanov 1969).

However, because of the low accuracy in the first method, and because of statistical heterogeneity and lack of observational data in the second, the results obtained by different authors were significantly different. The dependence of the relationship of light intensity to the linear electron density on the velocities in the range 11 - 31 km/s generally has not been investigated.

2 Dependences of Ratio of the Luminosity to Ionization on Velocity and Chemical Composition of Meteors

In this paper, on the bases of results of simultaneous optical and radio echo observations and the results of laboratory simulation of the luminescence and ionization, the correlation between the intensity of luminescence I_p to linear electron density q from the velocity and chemical composition of meteors are investigated.

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According to the physical theory of meteors, the ratio of luminous intensity I_f to the initial electron line density q is related with the parameters of the meteor body equation:

$$I_p / q = \tau V^3 \mu / 2 \beta \qquad (1)$$

where τ is the luminous efficiency, β - the ionizing probability, V- velocity of the meteor and μ - the mean mass of a meteor atom. According to the equation (1), the ratio I_p /q depends not only on the coefficients of luminous efficiency and ionization, but also on the velocity and chemical composition of meteor bodies.

To investigate the I_p /q from velocity and other factors, we used the results of parallel television and radar observations conducted during periods of maximum activity of meteor showers from 1978 - 1980 in Dushanbe (Narziev and Malyshev 2006, 2009), as well as the data of similar observations of the fainter ($4 < M < 8$) and low-velocity meteors ($10 < V < 36$ km/s) at Cambridge (Massachusetts) (Cook et al., 1973), the results of parallel photo - radar in Dushanbe (Babadjanov 1969), and the Jodrell Bank (Davies and Hall 1963). The basic equipment used for the observations, the method of processing the observational data and initial data on the individual meteors in the aforesaid sources are given in Davies and Hall (1963); Babadjanov (1969); Narziev and Malyshev (2006, 2009); and Cook et al. (1973).

Table 1 confirmed the following dates: N - number of the meteor, V - velocity, H - the height of the point of specular reflection, M and q - the absolute magnitude and the linear electron density at the point of specular reflection, I_p - luminous intensity, calculated from the known formula:

$$\lg I_f = 9.72 - 0.4 M \qquad (2)$$

The linear electron density for our joint meteors and meteor joint given in [2, 3], was determined from the measured duration of the radar echo. The value of lg I_p /q, calculated for each meteor is given in the sixth column, and in the seventh column source is indicated, which undertook the initial data. For meteors, given in Cook et al. (1973), the table gives the values of lg I_p /q calculated by n - Settlements.

According to the results given in Table 1, the calculated values of lg I_p /q are in the range -5.2 to -2.7. Figure 1 illustrates the distributions lg I_p /q and shows that the values lg I_p /q change in a fairly wide range from -5.5 to -2.5, with a maximum range of -5 to - 4.5. A large spread of values lg I_p /q, as already noted, possibly related to the dependence of the relationship lg I_p /q on the velocity and the difference in the chemical composition of meteors.

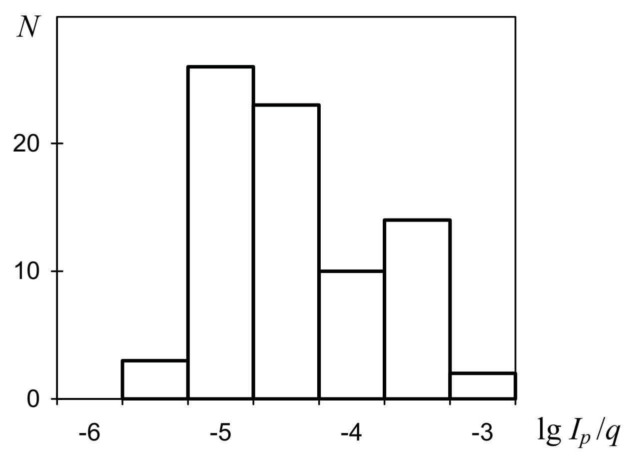

Figure 1. Observed distributions of ratio lg I_p /q.

Table 1. Ratio of luminous intensity I_p to the initial electron line density q by the results combined optical and radio observations of meteors.
(Sources: (A) Narziev and Malyshev 2006, 2009; (B) Davies and Hall 1963; (C) Babadjanov 1969; (D) Cook et al. 1973)

N	V км/с	H км	M	lg q	lg I_p/q	Source
1	56.70	104.4	1.50	13.70	- 4.62	(A)
2	36.50	92.0	1.10	13.60	- 4.28	--”--
3	59.99	102.9	- 0.30	13.96	- 4.12	--”--
4	-	98.0	- 0.90	14.73	- 4.55	--”--
5	43.90	101.0	- 1.50	14.60	- 4.28	--”--
6	40.80	99.0	1.63	13.16	- 4.22	--”--
7	57.90	102.3	1.90	13.67	- 4.71	--”--
8	46.20	105.0	1.10	13.98	- 4.70	--”--
9	40.10	92.0	2.50	13.98	- 3.67	--”--
10	21.90	86.0	0.20	13.07	- 3.43	--”--
11	41.40	96.3	1.60	13.60	- 4.52	--”--
12	29.10	90.0	- 1.60	15.08	- 4.72	--”--
13	39.20	95.1	2.20	13.56	- 4.72	--”--
14	29.90	92.3	2.16	13.11	- 4.25	--”--
15	43.40	92.0	0.50	13.77	- 4.25	--”--
16	41.80	91.6	1.90	12.60	- 3.64	--”--
17	41.80	93.0	1.70	13.44	- 4.40	--”--
18	40.60	92.6	1.80	13.30	- 4.30	--”--
19	40.20	92.0	0.20	13.97	- 4.33	--”--
20	30.80	90.9	1.80	13.28	- 4.28	--”--
21	47.70	102.2	2.20	13.49	- 4.65	--”--
22	44.97	93.5	1.60	13.50	- 4.42	--”--
23	42.90	92.7	1.20	13.45	- 4.21	--”--
24	40.80	98.9	2.50	12.88	- 4.16	--”--
25	41.40	94.2	1.00	13.83	- 4.51	--”--
26	37.50	98.5	2.50	12.84	- 4.12	--”--
27	31.00	88.0	-	13.11	-	--”--
28	22.60	86.5	0.0	13.73	- 4.01	--”--
29	43.90	95.0	1.40	13.70	- 4.54	--”--
30	14.30	88.5	- 1.00	14.21	- 4.09	--”--
31	69.40	110.5	- 0.15	14.59	- 4.81	--”--
32	60.90	102.4	1.50	13.55	- 4.43	--”--
33	60.90	106.4	-	14.36	-	--”--
34	62.20	107.5	0.80	14.20	- 4.80	--”--
35	38.50	91.4	- 1.00	14.75	- 4.63	--”--
36	38.00	84.2	0.0	13.34	- 3.62	--”--
37	40.90	87.0	2.05	12.33	- 3.43	--”--
38	52.90	106.6	0.22	14.50	- 4.86	--”--
39	55.50	106.1	2.05	13.92	- 5.02	--”--
40	57.80	105.8	2.28	13.88	- 5.07	--”--
41	59.90	104.1	1.00	13.76	- 4.44	--”--
42	60.90	106.7	1.10	14.04	- 4.76	--”--
43	55.70	102.5	2.00	13.64	- 4.72	(A)
44	63.60	99.0	- 1.75	14.77	- 4.35	--”--
45	65.80	102.0	- 1.20	14.84	- 4.64	--”--
46	63.90	102.7	1.82	13.62	- 4.63	--”--
47	58.10	106.2	1.50	13.99	- 4.72	--”--
48	62.20	106.0	0.80	14.20	- 4.75	--”--
49	65.70	101.1	1.53	14.09	- 4.98	--”--
50	62.30	103.5	1.05	13.63	- 4.33	--”--
51	59.80	105.5	0.20	14.29	- 4.65	--”--
52	60.50	102.5	1.50	13.56	- 4.44	--”--
53	60.40	100.8	2.60	13.27	- 4.59	--”--
54	65.70	99.0	- 3.20	15.71	- 4.71	--”--
55	55.00	105.2	1.40	13.85	- 4.69	--”--
56	61.00	108.0	1.70	14.27	- 5.23	--”--
57	56.10	106.3	0.40	14.12	- 4.56	--”--
1	37.00	94.9	- 1.7	14.99	- 4.59	(B)
2	40.00	110.3	- 1.80	14.88	- 4.44	--”--
3	29.00	92.8	2.00	12.19	- 3.27	--”--
4	27.50	81.5	2.70	12.54	- 3.90	--”--
5a	33.00	101.9	3.30	12.39	- 3.99	--”--
5в	33.00	96.5	1.60	13.75	- 4.67	--”--
6	34.00	96.4	1.60	12.39	- 3.31	--”--
7	26.00	89.0	1.50	12.88	- 3.52	--”--
661345a	71.50	97.8	- 6.30	15.93	- 3.69	(C)
661345б	71.60	97.3	- 4.40	15.19	- 3.71	--”--
670805	60.10	98.2	- 2.10	14.25	- 3.87	--”--
670821	60.50	99.0	- 2.90	15.28	- 4.40	--”--
670866	61.70	107.5	- 3.00	15.50	- 4.58	--”--
670931	61.00	95.0	- 5.80	16.73	- 4.69	--”--
670954	63.70	93.6	- 4.80	14.96	- 3.32	--”--
1	31.20	83.7	5.50	10.16	- 3.08	(D)
2	14.70	97.3	6.87	10.12	- 2.97	--”--
7	17.90	91.9	4.85	10.80	- 3.02	--”--
9	28.80	99.3	4.95	11.10	- 3.36	--”--
12	16.20	90.1	7.75	9.65	- 3.03	--”--
14	36.00	84.0	6.13	10.77	- 3.51	--”--
15	30.10	92.9	6.30	10.72	- 3.52	--”--
19	30.40	100.7	6.20	10.40	- 3.28	--”--
21	32.00	92.3	6.78	10.22	- 3.21	--”--
23	35.70	84.3	7.15	10.24	- 3.38	--”--
24	27.10	91.0	6.50	10.08	- 2.96	--”--
25	20.20	88.9	5.53	10.13	- 2.79	--”--

Dependence of lg I_p/q on the velocity are investigated by observations of 66 meteors that have absolute magnitudes, the prisoners in the interval $-1 < M < +8$. Meteors brighter than magnitude -1^m are excluded for the following reasons: a) In most of the observed cases, these meteors are registered on turning trails. The number of such meteors in our case was 7. b) In addition, bright meteors features with multicenter radio echo duration and displacement of the mirror reflection along the trail. These factors tend to lead to an underestimation of the values of the radio echo duration and the line electron density.

The rest of the meteors were divided into groups according to velocity intervals of 10 km/s and for each group the average value of V and lg I_p/q was calculated. The results are shown in Figure 2 (red circles), where the values of lg I_p/q are on the axis of ordinates and the X-axis shows meteor velocity. From the data presented in the figure, the ratio of lg I_f/q in the range 14 – 25 km/s does not change significantly, and it is shown that in further increasing the velocity to 62 km/s, this ratio decreases more than an order of magnitude.

According to the equation (1), the ratio lg I_p/q can be determined if we know the value of τ and β considering the given value of velocity and chemical composition. Such data for the velocity range of 11 - 53 km/s were obtained from laboratory simulation of the emission and ionization for particles consisting of Fe, Ca, Si, Mg, etc. (Becker and Friichtenicht 1971; Boitnott and Savage 1970; Boitnott and Savage 1971; Friichtenicht and Becker 1973; Slattery and Friichtenicht 1967).

These elements are the parts of stony meteoroids and are often observed in the spectra of meteors. The results of these experiments confirm the dependence of V on τ for model B (Lebedinets 1980). The dependence of β on V for the case of iron particles is obtained in the form (Slattery and Friichtenicht 1967):

$$\beta(Fe) = 1.5 \cdot 10^{-21}\ V^{3.12} \qquad (3)$$

By specifying the chemical composition of dust particles and the numerical values of τ and β according to these experiments, using equation (1), we can calculate the ratio of lg I_p/q for different values of velocity. The calculation results are shown in Figure 2 (white circles on the - Fe). Similar calculations are carried out for copper particles in Figure 2 (triangle Δ - Cu). As from observational data and the results of laboratory simulation it is shown that changing the value of lg I_p/q on the velocity of this change τ from V in model B. The differences between the curves is likely due to difference of chemical composition, partly to measurement errors that occur in the case of observations and data in the laboratory simulation, as well as conditions of the laboratory experiments, which correspond to heights of 70 km. On the basis of the results of simultaneous observations of meteors, lg I_p/q is found with velocity dependence:

$$\lg I_p/q = (6.66 \pm 0.73) - (1.63 \pm 0.35) \lg V$$

where V expressed in cm/s.

We can estimate the influence of chemical composition of meteoroids in the scatter in the value of lg I_p/q, using the results of laboratory simulations. To do this, from (Lebedinets 1980; Becker and Friichtenicht 1971; Boitnott and Savage 1970; Boitnott and Savage 1971; Friichtenicht and Becker 1973; Slattery and Friichtenicht 1967) we had taken numerical values of lg τ and lg β for the velocity V = 40 km/s. Data of lg τ and lg β are calculated values of lg I_p/q for micron-sized dust particles,

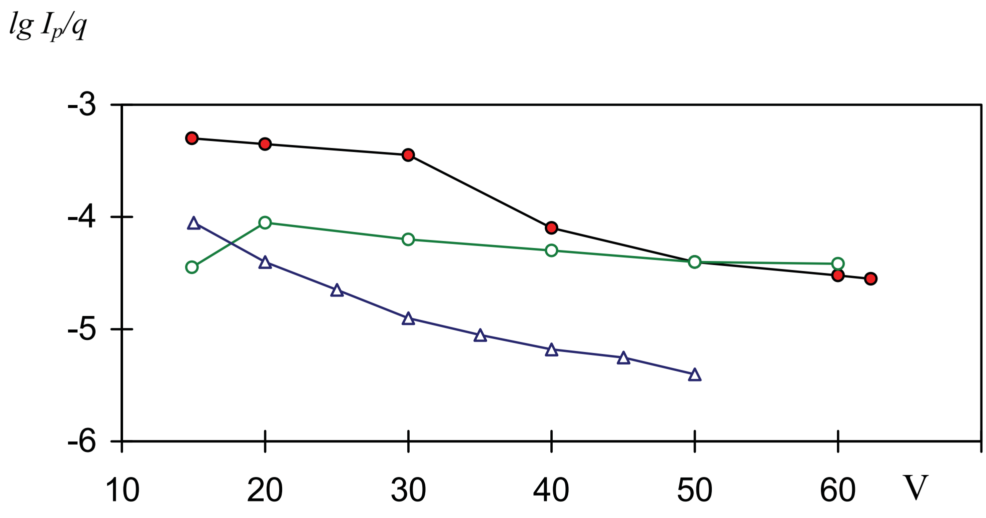

Figure 2. Variation of mean values of lg I_p/q as a function of velocity V.

containing in its composition Mg, Si, Ca and Fe are presented in Table 2. According to the results given in the table, the value of lg I_p/q is not constant, but in all probability is a function of the atomic weight of the substance. For a given value of the velocity, value of lg I_p/q depending on the chemical composition of matter varies from -5.46 to -4.33. If the observed values of lg I_p/q, according to the results of parallel observations at 40 to 42 km/s, vary in the range -4.52 to -3.43. The average observed value lg I_p/q at a velocity V = 41 km/s is -4.2. Thus, based on how the results of parallel optical and radar observations and data from laboratory simulation of the emission and ionization, it follows that the ratio of light intensity to a linear electron density is a function of velocity and chemical composition of meteors.

Table 2. Ratio of lg I_p/q as a functions of chemical composition of the substance.

Elements	lg τ	lg β	lg I_p/q
Mg	- 3.40	- 0.821	- 5.46
Si	- 2.97	- 0.523	- 5.27
Ca	- 2.88	- 0.208	- 5.33
Fe	- 2.03	- 0.225	- 4.33

3 Conclusions

1. For the range of meteor velocities from 14 to 71 km/s and a brightness of up to 7^m – -7^m meteors obtained as a result of parallel optical and radar observations, we calculated the ratio of the logarithm of light intensity to a linear electron density. It was found that the calculated values of the ratio of light intensity to the linear electron density in the range -5.1 to -2.7. The average value of lg I_p/q is -4.5.

2. According to the results of parallel optical and radar observations and the data of laboratory modeling of the phenomenon of a meteor, we studied the relation between the logarithm of the ratio of light intensity to the linear electron density lg I_f/q on the velocity and chemical composition of the meteors. It is received from simultaneous results observations of meteors, and results of laboratory

modeling follows that by increasing value of velocities of meteors lg I_p /q decreased more than one order.

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