THE NATURAL THERMOLUMINESCENCE AND ORBITS OF METEORITES.

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Introduction: The only way to obtain an accurate orbit is to simultaneously photograph the trajectory of the fireball from two or more widely separated locations. Several photographic networks [1] have been established to do just this. After almost 40 network-years of operation, however, these efforts have led to the recovery of only four meteorites: Pribram [2], Lost City [3], Innisfree [1] and Peekskill [4]. Orbital parameters have been estimated for another 40 meteorites from eyewitness accounts of their fall [5,6] but these are of low accuracy. Limited orbital information can also be obtained from the local time of fall [7]. Meteorites with perihelia q ~1 astronomical unit (AU) should usually strike the trailing side of the Earth, or the local PM, while meteorites with perihelia q<1 AU should be more evenly spread over the leading and trailing sides. The large abundance of ordinary chondrites falling in the local PM relative to AM is interpreted as indicating that most of these meteorites had perihelia of ~1 AU.

Periodic changes of the perihelion of chondrites during their cosmic-ray exposure history (up to ~n10^7 years) may stipulate diffusion losses of gases at q ≤0.2 AU (temperatures T≥400 °C) and reaccumulation of natural thermoluminescence at q ~1 AU during the last of ~10^5 years before capture by the Earth.

Thermoluminescence (TL) is an extremely useful technique for studying the metamorphism and recent histories of meteorite [8]. The induced TL of meteorites is predominantly controlled by the type and abundance of feldspar present, while the level of natural TL (TL of the sample "as received") is determined by the thermal and radiation history of the sample. In this study we use the natural TL of individual meteorites to estimate their closest approach to the Sun. Natural TL is energy stored in crystals of certain minerals by ionizing radiation, such as high-energy galactic cosmic rays [9,10]. This energy can be released in the form of visible light by heating. The experimental procedures have been described in more detail earlier [11-13].

Perihelion of the orbits: During occurrence in orbit, natural TL is accumulated in meteorite owing mainly to cosmic ray radiation. The natural TL level of a meteorite is initially very low because of shielding from cosmic radiation by its parent body. After the impact, which actually produces the meteorite-sized body (meter-diameter or less), natural TL levels build up relatively rapidly, reaching a state of "equilibrium" within about 10^5 years [8]. The level of natural TL, at least in the lower temperature and less thermally stable portion of the glow curve, is then in a state of dynamic equilibrium, varying slightly during each orbit as the TL drains slightly at the higher temperatures of perihelion which it regains at aphelion. The level of TL in the higher temperature and more thermally stable part of the glow curve is, however, relatively unaffected by orbital temperature variations and may reach saturation level at exposition by the cosmic rays for a sufficiently long period of time. The average level of low-temperature equilibrium TL can vary over the time span of 10^6-10^7 years if the meteoroid experiences changes in its long-term orbital parameter. After fall on the Earth, the natural TL levels gradually decrease to lower values as a result of the higher terrestrial temperatures and lower dose accumulation rates [14-16]. TL levels are also lowered by heating during atmospheric entry, but this only affects a thin (< 5 mm in thickness) outer rim of the meteorite..

The TL levels are within 20-80 krad (at T~250°C on the glow curve) in the most ordinary chondrites with known fall dates [17-19]. Calculation of the value of the equivalent dose of natural TL in ordinary chondrites allows us to suggest that the intensity of TL is a sensitive indicator of their degree of heating by Sun at passing the perihelion. In fact, at the lower the perihelion, we will have the higher the heating and the lower the equilibrium TL. Chondrites having orbits with the perihelion q <0.85 AU must show very low levels of natural TL (<5 krad at T~250°C on the glow curve), whereas those with q >0.85 AU must show wide ranges of natural TL values (>5 krad) with a considerable scatter related to the variations in the rate of dose accumulation (at a varying degree of shielding and albedo) [17]. However, comparison of the thermal and radiation histories of meteorites solely on the basis of natural TL is hampered by considerable variations in the sensitivity of TL accumulation in different meteorites. Thus, it appears reasonable to normalize the intensity of natural TL in each sample to its sensitivity through the measurement of the TL value per unit dose induced by a radioactive source. The ratio known as equivalent dose (ED) is determined for each temperature value of the glow curve using the formula:

$$ED = D\,(TL_{nat}/TL_{ind}),$$

where TL_{nat} and TL_{ind} are the natural and induced TL, respectively, and D is the dose of laboratory radiation (rad). Using such an approach, Melcher [20] estimated the perihelia of 45 meteorites. However, investigations suggest that it is more reasonable to calculate ED for two temperature intervals on the glow curves; ED_{LT} at T~100-240°C and ED_{HT} at T~240-340°C. This allows us to reduce the error of ED estimate to ≤ 15% and estimate more accurately the perihelion value.

Comparative measurements of natural TL and TL, induced by γ-radiation, and calculations of ED_{LT} and ED_{HT} using a special program were carried out for 21 chondrite samples (See Table). Some of these chondrites were studied in [20], including the Pribram chondrite with a known orbit. The ED values of Pribram correspond to its perihelion (q=0.8 AU) and coincide with the results of ED measurements reported in [20]. For the majority of chondrites, including Bjurbole L/LL4, Chainpur LL3.4, Dalgety Downs L4, Dhajala H3.8, Gorlovka H3.7, Grady H3.7, Elenovka L5, Khohar L3.6, Kunashak L6, Kunya-Urgench H5, Kyushu L6, Mezo Madaras L3.7, Nikol'skoe L4/5, Ochansk H4, Pervomaisky L6, Pultusk H5, Rakity L3.6, and Saratov L4, the perihelia of orbits (q) are within - 1.0-0.8 AU. Lower perihelia were determined only for the L5 chondrites Malakal (q~0.5-0.6 AU), which is consistent with [20], and Dimmit H3.7 (q~0.6-0.8 AU). A value of q~1 AU was obtained for the Kunya-Urgench orbit, which agrees with the perihelion estimate from the radiant of the chondrite fall [21].

Table. Equivalent doses (rad) for meteorites

Meteorite	Type	ED_{LT}	ED_{HT}
Biurboele	L/LL4	38 ± 5	156 ± 4
Chainpur	LL3.4	5.7 ± 1.2	77 ± 21
Dalgety Downs	L4	0.23 ± 0.02	30.1 ± 5.6
Dhajala	H3.8	1.7 ± 0.1	21 ± 1
Dimmit	H3.7	0.6 ± 0.3	10.6 ± 6.1
Elenovka	L5	3.9 ± 0.3	23 ± 2
Gorlovka	H3.7	46 ± 15	288 ± 44
Grady	H3.7	1.4 ± 0.4	80 ± 11
Khohar	L3.6	1.21 ± 0.16	51.3 ± 1.4
Kunashak	L6	16.6 ± 2.0	43.2 ± 7.0
Kunya-Urgench	L5	11.2 ± 1.0	100 ± 8
Kyushu	L6	30.0 ± 5.6	181 ± 11
Malakal	L6	1.2 ± 0.1	2.4 ± 1.0
Mezo Madaras	L3.7	35.5 ± 4.6	368 ± 59
Nikol’skoe	L4/5	16.1 ± 0.7	159 ± 15
Ochansk	H4	10.7 ± 1.1	105 ± 10
Pervomaisky	L6	20.1 ± 1.9	71 ± 12
Pribram	H5	11.4 ± 1.5	127 ± 12
Pultusk	H5	4.6 ± 0.9	81 ± 15
Rakity	L3.6	12.9 ± 3.0	309 ± 25
Saratov	L4	17.1 ± 1.1	56 ± 5

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