In the experiments published earlier, fixed volumes (10 ml) of reactants in every case in the 150 ml reaction flask might have been subjected to same kind of stirrer-induced agitation to yield half times clustering in the range of 20-26 seconds. We feel that such long half times can not be attributed to the kinetics of carboxylic acid–sodium bicarbonate reactions. Most likely the results published earlier pertain to carbon dioxide escape kinetics under the experimental conditions.

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Meteors – The Terrestrial and Celestial Connection

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Introduction

Shooting stars or meteors have fascinated mankind from times immemorial. While it took centuries to realize that they have nothing to do with the stars, the exact physics was understood only in the last couple of centuries. Looking back into the pages of history we note that the study of the phenomenon itself starts with Aristotle's comment that the meteors are atmospheric events. Two hundred years ago, the debate was on their origin – whether celestial or terrestrial?

But we must first know what meteors are. These tiny particles weighing less than a gram float around in the vast space (believed to be almost empty) outside the earth's atmosphere and a chain of complex physical events are created as they enter the atmosphere. They are referred to as meteroids. Depending on the size of the particle, the effects can differ by orders of magnitude. The German duo Heinrich William Brandes and Johann Friedrich Benzenborg were the first to calculate the height at which meteors exist. They did this by the simple

The height at which meteors exist can be calculated by the simple method of triangulation.

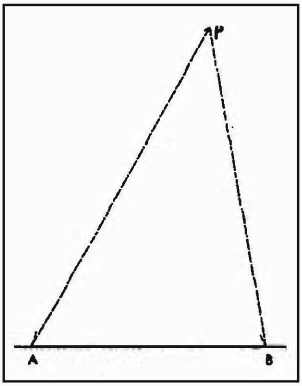

Figure 1. The method of triangulation. Observers at A and B will measure the angles PAB and PBA. The triangle can be reconstructed to get the altitude of an object at P.

method of triangulation. They chose a small baseline of about 15 kms to estimate the parallax, which is the angular separation of the meteor track with respect to the stellar background [1]. The result obtained from such measurements by the German scientists for meteors was an astonishing small height of a mere 100 kms. This places them within the earth's atmosphere (*Figure* 1). But the most important question pertained to the cause of the phenomenon itself.

The Terrestrial Connection

A systematic observation of meteors by the early risers reveals certain characteristics pertaining to the phenomenon of meteors.

1. There are more meteors at dawn than at dusk. (*Figure* 2).

2. Occasionally, there is a tremendous increase in the number of meteors.

3. All meteors are not alike. Some are bright, some are faint.

4. Some vanish without trace while others may leave a trail which slowly disintegrates over a time of 10 to 12 seconds.

[1] For example an aircraft flying high will appear overhead for one person while for another, placed a few kms. away, it may be in a different direction, which is decided by the separation as well as the height of the aircraft.

The word meteorite by definition refers to a stone like body that reaches the earth. The word 'meteor' itself means the phenomenon of burning up of the meteorite. The meteoric particles are known to approach the earth with speeds as high as 70 to 80 kms/second. The immediate effect of the plunge of the particles into the atmosphere is a drastic reduction in their speeds. The

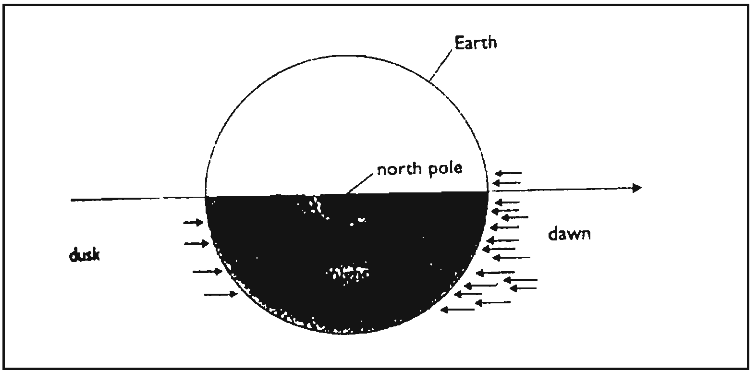

Figure 2. There are more meteors at dawn than at dusk. The rotation of the earth carries the meteor towards dawn. Bright half represents the 'day' and dark half the 'night'. The earth moves in the direction of the arrow.

atmospheric particles get adsorbed (attached, in a simple sense) on to the surface of the meteoric particle. The deceleration experienced will be decided by the drag coefficient[2], area of the meteoroid exposed to the air flow, the density of air and the velocity of the meteoroid itself. The rate of momentum lost by the particle of mass m may be mathematically written down as

[2]A constant decided by the density and other properties of air molecules at that height.

$$m\mathrm{d}v/\mathrm{d}t = -\Gamma S\rho v^2 ,$$

where Γ is the drag coefficient, m the mass of the particle, S the midsectional area and v the velocity.The effect of adsorption is just not the deceleration. Each adsorbed particle kicks out hundreds of molecules of the meteorite. This process is known as *ablation*.

Thus part of the energy of impact is used in evaporating a mass dm of the meteorite. The exact amount is decided by the latent heat of vaporization and the heat transfer coefficient. It is proportional to the kinetic energy. Mathematically,

$$\mathrm{d}m/\mathrm{d}t = -\Lambda S\rho v^3 / 2Q ,$$

where Λ is the heat transfer coefficient, Q the latent heat of vaporization, dm/dt the rate of ablation. According to the estimates of G H Walker, a large fraction of the impact goes into heating the meteorite. Thus the slow meteors use 0.01 % of their energy for heating while the fast ones use as much as 0.1%.

The atoms of the air are ionized by the swift passage of the meteor. Thus electrons are also created along the trail. There is an eventual recombination between the ion and the electron resulting in the emission of a specified quantum of radiation well known to spectroscopists. This can lead to bright yellow or green or even orange trails. Thus light associated with the meteor is due to the process of recombination in the ionized atoms. Quite obviously the radiation intensity and the electron density are decided by the vaporization rate. This idea forms the basis of the fundamental equations of the physics of meteors. Radiation intensity is proportional to the rate of evaporating

Light associated with the meteor is due to the process of recombination in the ionized atoms.

The spectrum of light that is finally emitted depends on various processes like evaporation, excitation, ionization and the intrinsic properties of the meteor material.

mass dm/dt, the velocity and the coefficient of radiative efficiency τ

$$I = \tau(-\mathrm{d}m/\mathrm{d}t)\, v^2 / 2.$$

The spectrum of light that is finally emitted depends on various processes like evaporation, excitation, ionization and the intrinsic properties of the meteor material. The net effect of all these is to completely use collision energy in deceleration, evaporation, etc. This results in a complete destruction of the intruder by ablation.

An analysis of the above processes can throw light on the origin of meteorite itself. Many laboratory experiments were conducted to identify the various constants that are involved in the above equations. Allen and Baldwin tried to understand the process of ablation by working on the various rock and meteorite samples. Their photograph of the ablation in these substances resembles the actual photograph of the process taken recently by balloon borne measurements, testifying their methodology. A paper in the *Astrophysical Journal* of 1953, by Thomas and White gives the theoretical aspects.

The spectra serve an important purpose in identifying the constituents of meteors. Long ago, Alexander Herschel attempted to see the spectra by attaching a prism to the binoculars. Subsequently the same method was employed by several others to identify the atoms and molecules that participate in this colourful event. Since the tiny particles approach the earth from all directions it is impossible to catch them on a photograph; so, the recording of the spectrum is still far from being practical.

The pioneering work on a systematic study of the spectra of meteors was taken up by Halliday in the sixties. In a series of papers in the *Astrophysical Journal*, the detailed analyses have been reported. The spectra show a very strong line at 557 nanometers corresponding to oxygen. This is represented as [OI] and called the forbidden line of oxygen. The lines corresponding to the negatively charged nitrogen molecule are also seen. But what are forbidden lines? The spectral lines arise from transitions of electrons from higher energy to lower energy levels. These have certain probabilities, which are decided by the quantum mechanical selection rules. Forbidden lines are the least probable and therefore cannot be seen in a laboratory spectrum. Before the transition takes place, the collisions between the atoms change the energy configuration.

There is a connection between meteors and showers.

The Celestial Connection

The phenomenon of meteoric showers was made known to the scientific community by a pair of natural scientists, Alexander Von Humboldt of Germany and Aime Bonplande of France, from the wilds of South America. They counted thousands of meteors within about two hours. That the natives were aware of this 'show' on that particular day of the year added to their surprise. That was not all – they even knew that once in every 33 years it was a real big show.

Soon a systematic documentation of the meteor activity began. These astronomers were rewarded with as many as 200,000 meteors in about 6-7 hours in the year 1833. Dennison Olmstead studied the showers and found that the meteors appeared to originate from a fixed point in the sky. This point, called the *radiant* (*Figure* 3), rises in the east and moves like any other celestial body. It reaches the zenith by about day break. The position of the radiant was specified by the associated constellation. Thus there were Leonids, Aquarids, Orionids. All these were seen by the Belgian astronomer Adolphe Quetelet in 1839. Schiaparelli, of the 'Canals on Mars' fame, and Angelo Secchi precisely identified the radiant as a point located in the orbit of a comet. This point happens to be the node, the point of intersection of the orbit of a comet with the ecliptic, that is the earth's orbital plane. Thus there is a connection between meteors and showers. For example the Perseid meteor showers with the peak on August 12th were associated with the great comet Swift–Tuttle of 1862. The same argument can be extended to other showers. The Orionids and Aquarids are associated with comet

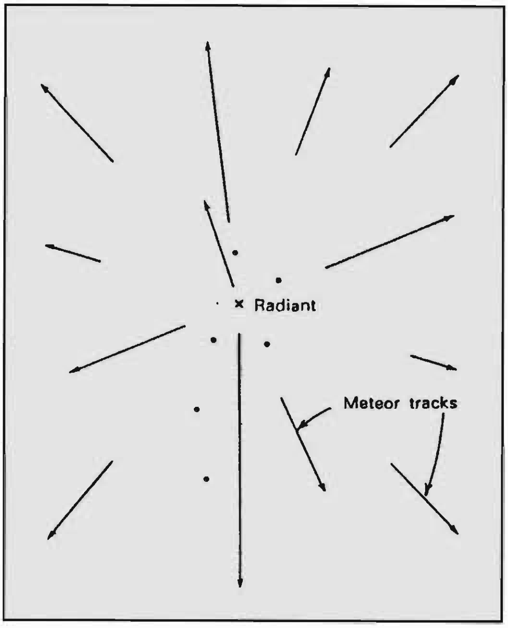

Figure 3. The radiant is a point in the sky. Just as the parallel railway tracks appear to diverge near the observer, the meteors from a single point appear spread all over the sky. By joining the apparent tracks one may identify the position of the radiant.

Halley. Leonids association with the comet Temple–Tuttle, gained importance after its visit in 1866. A comet of a very short period of about six years provided an opportunity to strengthen the tie between the comets and the showers. This was studied by Biela, whose name got associated with it. Its passage in 1846 was noticed with great interest because it split into two. The comet pair returned after six years and subsequently both pieces were lost. However, on the expected date of encounter with the node, there was a 'shower' of meteors.

It has now been established that the comets are 'dirty snow balls' with much of their mass in the form of particles in the tail. The complex molecules like cyanogen, carbon dioxide and water, which are frozen on their surface, evaporate as the comet approaches the sun. These form the tail of the comet and eventually are lost from the comet. They spread along the comet's orbit and on every encounter with the earth we get showers.

Owing to the fact that the orbits of comets have high inclinations to the ecliptic, the earth may chance upon both the ascending and descending nodes of the orbit. Thus Comet Halley accounts for two showers in a year once in May and again in October (*Figure* 4). The passage of the earth close to the radiant just after

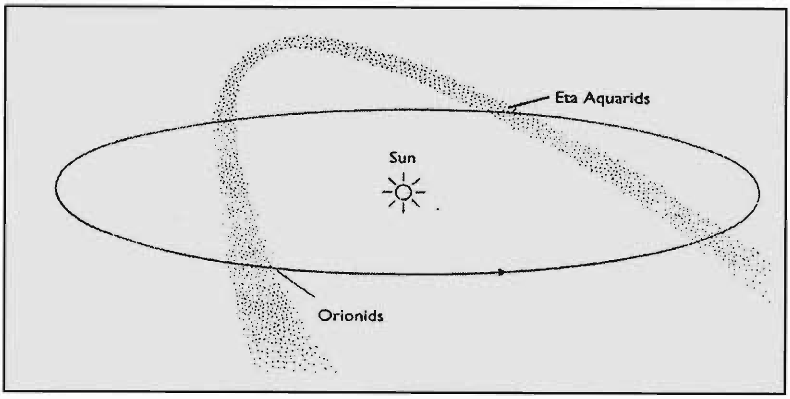

Figure 4. The nodes of the orbit of comet Halley. Earth approaches them twice in a year creating Eta Aquarids in May and Orionids in October. Continuous curve is the earth's orbit and the mottled region the dust left in the comets orbit.

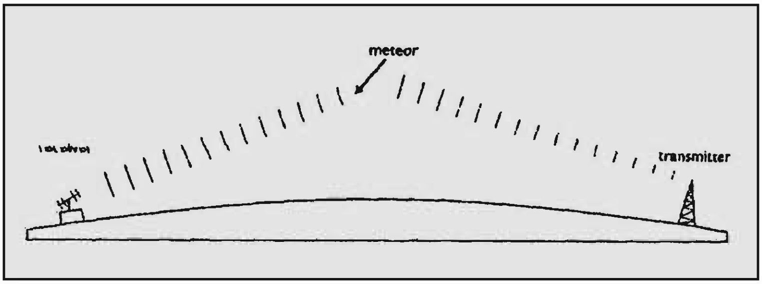

Figure 5. The reflection of radio waves by meteor trail is caused by the temporary ionization of the air molecules.

the perihelion passage of the comet would produce a storm of meteors since the stock would have been just then replenished. The comet Temple–Tuttle visited the sun in 1997 – hence the excitement about the Leonids.

Radio Observations

The ionization of the air molecules for a short duration can reflect the radio waves as effectively as the ionosphere. (*Figure* 5) Thus certain radio frequencies are specially reflected by the trail. A simple calculation involves the knowledge of the electrons that are available in the trail. This reflection of radio waves is within the frequency reception of certain FM stations and HAM (amateur) radio operators. Thus they can 'hear' the meteor. It produces a characteristic ping for a brief period.

The duration over which a trail can echo the radio signals is decided by various parameters like electron density, the rates of diffusion of the trail, radius of the trail as it expands and so on. The effect is noticeable in the range 4 to 10 meters of wavelength. They are classified as overdense, transitional and underdense trails. If the electron density is less than 2.4×10^{12} electrons/cm, the radio waves can penetrate the trail. These are the underdense trails. The interesting part is that the observability hits a peak at some intermediate value of the velocities of the meteors. This value ranges from about 30 to 50 km/s. For lower velocities the ionization is not strong enough, while for higher velocities the trail radius drastically reduces. A detailed mathematical analysis of these situations has been provided by Bronshten. This method can be used to establish the peak activity of the shower even during the day time and in the cloudy skies as well. There is an

FM stations and HAM (amateur) radio operators can 'hear' the meteor. It produces a characteristic ping for a brief period.

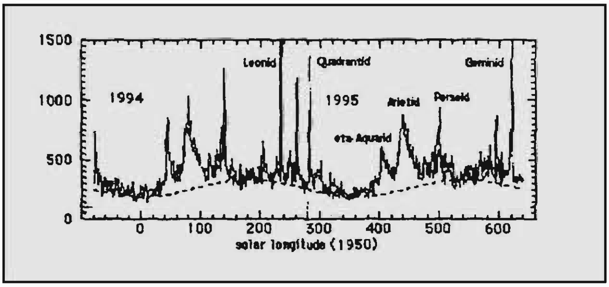

Figure 6. The radio meteors record the peak of shower. (reproduced from Jenniskens, http://www-space.arc.nasa.gov/~leonid/GlobalMSNet.html)

arrangement to keep the transmitters on, round the clock, so that the timing of the signals and their strengths can be monitored (*Figure* 6).

Visual Observations

Inspite of all the sophistication in the study of other celestial phenomena, the best study of meteors is possible only with the naked eyes. A long exposure on a film can only be the next best. This demands absolutely no extraneous light interference, not even from the moon. The star trails and the random meteor trails get recorded and the film can be later on used to establish the radiant. The gradual shift in the position of the radiant can be interpreted in terms of the dynamics of the cometary particles. A camera with a rotating gate in front of the shutter can be used to measure the speed of the meteor. The meteor leaves behind a trail of dashed lines, the interval corresponding to the rotating speed of the gate. A fisheye lens can be mounted on a camera and the shutter may be kept open for very long duration. However, this photograph cannot be used for making precise measurements. The microbiologist Neil Bone has devised a six camera arrangement to get a maximum sky coverage. Stefan Evans has further modified it into an automatic system with a rotating gate common to all the six cameras.

The best study of meteors is possible only with the naked eyes.

Finally, a word about the timings of the shower due to occur next month (*Box* 1). The calculations here involve unseen particles. Moreover, their distribution is not very well known. The particles may be concentrated at one point, which need not be at the node. Therefore the calculations which are carried out with certain assumptions lead to different timings of the event.

Box 1.

The fast moving rocky pieces can sometimes be large enough to reach the earth without completely burning. Quite naturally, they emit lot of radiation which can be recognized even in day time. They appear to move along the horizon. In the night they can match the full moon in brightness. Very few of such bolides have been recorded by camera. The most interesting one appeared on the cover page of Sky and Telescope in 1974. A couple of months back another was reported from New Zealand.

The November 17, 1998, Leonid meteor shower offered the most intense display of bolides since the storm of 1966. NASA Ames Research Center launched an airborne campaign with the goal of studying the chemistry and physics of extraterrestrial matter falling into Earth's atmosphere. Scientists traced the dust trails, which give us valuable insight into how meteor showers are formed. The high rates resulted in a bounty of data like the first detection of molecules, the debris of iron atoms, the heat of meteors, and the first images of meteor trails, probed by powerful lasers. Heat-seeking telescopes of the Aerospace Corporation onboard the FISTA aircraft in the mission made an effort to detect the heat of meteors and measure how fast the gas cools off. The University of Illinois fielded two powerful lasers onboard the second aircraft in the mission called the Electra. The lasers probed the debris left behind in the path of the meteors. The metal atoms deposited by meteors persist much longer in the atmosphere than thought before. This may help us learn how the meteoric debris can settle to Earth's surface and catalyze chemical reactions. A 10m weather balloon was launched into the stratosphere and captured tiny particles 20 km above Earth's surface.

In November of this year, Earth makes another close encounter with this dust trail, when a meteor storm may occur over Europe and Africa. We may expect to see more bodies prior to and after the exact passage through the node.

The predicted time of occurrence on the previous occasions has varied from ± 30 minutes to ± 14 hours. The predawn areas on the earth provide the best opportunity to view the celestial show. Elsewhere only the declining phases of the event, which are equally interesting, can be seen. One may have to keep one's fingers crossed and watch for a couple of days prior to and after 17th November 1999.

Suggested Reading

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