On the Glitter of a Meteor

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Chunks of stony materials dashing into the Earth's atmosphere evoke awesome moments of fascination. Laymen generally interpret these dazzling displays of nature as 'meteors'. In this article, various aspects of astronomical and atmospheric meteors are discussed.

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Introduction

The Earth shares its environment in the inner portion of the solar system with a variety of solid objects that range widely in size. Collisions between these objects and the Earth produce 'astronomical meteors'. The phenomena associated with the encounters vary from insignificant ones to dazzling displays, to catastrophic displays and even to catastrophic disasters. In the common language, meteors always refer to the extraterrestrial sort. However, non-astronomical meteors are even more common, and they are generally known as 'atmospheric meteors'.

The astronomical meteors provide us with the clues for determining the processes accountable for the origin of our solar system, as the fragments of the solid material penetrating the Earth's atmosphere and which succeed in reaching the Earth's surface contain differentiated as well as undifferentiated materials. The meteorites, which are fragments of differentiated parent bodies, provide information about fractionation processes in planetary interiors. The undifferentiated ones consist of particles collated before the initial warming up occurred and of materials that cooled down and transported from deep space to reach the Earth, as the signatures of the past.

Meteors

Keywords
Meteors, meteorites, atmospheric meteors.

The word 'meteor' comes from the Greek word 'meteora' which stands for 'things in the air', which is appropriate since meteoric activity is observed in the upper atmosphere. Meteors are familiar to everyone who has watched the night sky for more than a few minutes. The meteor phenomena occur when an interplanetary dust particle travelling at high speed enters into the atmosphere of the Earth and ablates due to friction with the atmospheric constituents. The usual result is a brilliant streak of light moving across the night sky known as a meteor or more commonly as a 'shooting star'. However, meteors are not stars; only their appearance has given rise to their common name. In another usage, the term meteor is applied only to the visible trail, the particle itself being termed meteoroids.

Meteors are grouped as 'meteor showers' and 'sporadic meteors'. Meteor showers may be seen by an observer in any part of the sky visible to him. Meteor showers comprise parts of great streams of particles orbiting the Sun; they are mostly associated with comets and appear to enter the atmosphere from those points of the sky and around those calendar dates given in *Table* 1. It was the vague similarity to rainfall that led to the term meteor showers and the phrase is also used to describe much less impressive display in which an increase in the normal frequency of meteors is observed.

A meteor's flight path in the atmosphere deviates imperceptibly from a straight line. An observer exactly on the projection of this line would see the meteor coming 'head on' with no apparent motion in the sky, i.e., he would see a 'point' meteor instead of a line. The location of this point in the sky is the apparent direction from which the meteor approaches the Earth and is called the 'radiant', and the effect of the common radiant direction is that if the luminous paths are projected backward, they will appear to diverge or radiate from a single point. Meteor showers are usually termed after the constellation in which the radiant is located or after a particular star near the radiant.

The meteor phenomena occur when an interplanetary dust particle enters the atmosphere.

Sporadic meteors are of random occurrence, which account for the bulk of the total meteor activity.

Meteor Visibility

A single observer on a dark moonless night may expect to see about six meteors per hour. Few of these will endure for more than half a second, and rarely longer than one or two seconds. They are generally more abundant after midnight than before and are decidedly more common on some nights than on others, as detailed in *Table* 1. Faint meteors are more numerous than bright ones, so the total number seen depends mainly on the quality of the observing conditions.

From synchronized meteor observations at a known distance apart, the velocity, brightness, and the heights of appearance and disappearance of individual meteors may be measured. Such observations show that most visible meteors appear at about 110 km and disappear at about 80 km, with a secondary maximum frequency of disappearance at about 45 km and a minimum frequency at 55 km [1].

Meteor Masses

The amount of light emitted by a meteor is closely related to the

Table 1.

Meteor shower	Active between (From -to)	Right Ascension of the radiants	Declination of the radiants (degrees)	Notes
Quadrantids	01 Jan. - 06 Jan.	$15^h\ 28^m$	+50	Blue and yellow meteors
Lyrids	19 Apr. - 25 Apr.	$18^h\ 16^m$	+34	Moderatively active shower
η-Aquarids	24 Apr. - 5 May	$22^h\ 27^m$	00	Multiple radiant broad maximum
δ-Aquarids	15 July - 18 Aug.	$22^h\ 38^m$	−16	Double radiant, faint meteors
Perseids	23 July - 22 Aug.	$03^h\ 06^m$	+58	Rich shower, with bright meteors
Orionids	16 Oct. - 27 Oct.	$06^h\ 22^m$	+16	Fast meteors
Taurids	20 Oct - 30 Nov.	$03^h\ 44^m$	+14	Slow and bright meteors
Leonids	14 Nov.- 20 Nov.	$10^h\ 08^m$	+22	Fast meteors
Geminids	07 Dec.- 16 Dec.	$07^h\ 28^m$	+32	Rich shower of medium speed meteors

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mass of the particle consumed. They frequently display a nearly straight or gently curving trajectory so that a very small mass is indicated. The brilliance reflects the kinetic energy and calculations confirm that most meteors are only of a milligram scale. However, the largest fireballs are known to furnish meteorites of up to several tonnes. The estimates of meteor masses are complicated by the variation in velocity of the meteor and by the tendency of most meteoroids to break into numerous fragments. Since the rate of burnout of a meteor is a function of air density, the density and hence the temperature of the air may be calculated from data. The radio echo technique has been used with the ionized trails produced by meteors in order to determine density, temperature, and winds at the atmospheric levels concerned.

Box 1. Meteoroids

A meteor may also be stated as a heated, glowing 'meteoroid' in transit through the atmosphere. Technically a meteoroid is the solid object itself either in space or during flight in the atmosphere, and the vapour trail produced by the passage of the meteoroid into the atmosphere is the most often observed optical phenomenon of the meteor.

Types of Meteors

'Fireballs' are the very brightest and infrequent meteors. They can be much brighter than the full moon, and in rare cases rival the Sun and are often measured down to about 25 km. A fireball may explode in the sky. It is then called a 'bolide'. 'Radiometeors' are the ones that causes a reflection of radio signals due to the high ionic density of their trail in the upper atmosphere, 80 to 120 km, especially in the upper layer. Maximum signals are received from transmissions crossed at right angles by the meteor course and signal strength of a regular radio or radar transmission may briefly reach a very high peak. 'Whistling meteor' is the result of a Doppler effect of a radio meteor when an unmodulated radio transmission reflected by the meteor passes. 'Photographic meteor' is simply one bright enough to be recordable on a light-sensitive photographic emulsion plate.

Meteorites

In those relatively rare events in which solid pieces of stone or metal survive the atmospheric passage, the objects that reach the Earth's atmosphere are termed 'meteorites'. A meteorite fall is invariably accompanied by a fireball in the atmosphere, but many fireballs, even great ones, may yield no surviving meteorites. Dust-size particles of interplanetary matter that may filter through the atmosphere with or without being melted are called 'micrometeorites'. These are very small meteorite or meteorite particles with diameters in general less than a millimetre. Thus, micrometeorites can be fragments of meteorites that have undergone collisions in space; fragments of meteorites that have been plucked from the main mass during passage through the Earth's atmosphere; fragments of meteorites separated from the main mass upon impact with the Earth tiny meteorites that were created in the same process that created the larger meteorites but with smaller diameters. They would be expected to have the same range of compositions as the meteorites, ranging from predominantly metallic nickel-iron alloy through siliceous (stony) meteorites with little or no metallic phase. So, meteorites are classified into iron, stone and stony-iron meteorites, respectively (*Figure* 1).

Iron meteorites consist mainly of a solid solution of nickel and

Figure 1. a) Chondrite Meteorite: This meteorite was collected from the Allan Hills in Antarctica. This meteorite is of a type named chondrite and is thought to haved formed at the same time as the planets in the solar nebula, about 4.55 billion years ago.

b) Achondrite Meteorite: Discovered at Reckling Peak, Antarctica, this type of meteorite is known as an achondrite. It has a basaltic composition and was probably formed when an asteroid melted about 4.5 billion years ago. The asteroid broke up some time later and this small piece of the asteroid was captured by Earth's gravity and fell to the ground.

c) Iron Meteorite: This iron meteorite was found at Derrick Peak, Antarctica. This type of meteorite gets its name because it is mostly made of the elements iron and nickel. This sample is probably a small piece from the core of a large asteroid that broke apart.

(Courtesy NASA/JPL)

iron with minor elements of cobalt and phosphorus. Frequently, small inclusions of stony material are present within the nickel-iron solution. Nickel content of 8% is normal, but different subclasses range from 5 to 19%. Typical irons are nearly eight times as dense as water, are dark or rusty in appearance, and the outer surface frequently exhibits signs of uneven ablation during flight through the atmosphere.

Stone meteorites are also called 'aerolites' and account for more than 90% of the meteorites falling on the Earth. Once the dull–black fusion crust weathers away, they become difficult to recognize. They consist of a wide variety of minerals, many of which are not found in rocks on the Earth's crust, and abundant small grains and veins of metallic nickel-iron, often 5% to 20% by weight, contribute magnetic properties. Often there are 'chondrules', small spheres of stone, which are less than 2.5 millimetre in diameter, that appear to have been molten drops at some stage prior to the formation of the meteorites' parent body. Stones, which contain chondrules, are classified as 'chondrites' and 'achondrites', which do not contain chondrules.

The parent body from which the achondrites originated e.g. an asteroid appear to have been molten and differentiated. Stones also include 'carbonaceous chondrites', which are rare but very important. They contain 8% to 22% of water in hydrated minerals and a wide variety of organic compounds including amino acids.

Stony iron meteorites are rare, representing about 1% of observed falls. They consist of roughly equal proportions of stony material and nickel-iron metal.

The Astronomical and Atmospheric Connection

Most of the meteoroids intercepting the Earth's atmosphere have a velocity of 11 to 72 km/s. Because of its large entry velocity, an inward bound meteoroid from space ablates as it encounters the denser regions of the atmosphere at the altitude range of 80 to 120 km which is referred as 'the meteor region'.

The meteoroids, which resist the burnout by atmospheric friction, may end up as meteorites either in the Earth's terrestrial surroundings, or in the ocean and become a part of the oceanic sediment.

The debris, which comprise metallic ions and atoms resulting from the meteoroid ablation, is usually dispersed in the atmospheric column. The most abundant metallic ions include Fe^+, Mg^+, Al^+, Ca^+ and Na^+. Elements typically found include oxygen, iron, nickel, silicon, calcium, magnesium, sodium, lithium, sulphur, manganese, chlorine, potassium, titanium and cobalt. Most of this material is vaporized, melted, or otherwise lost on the way down through the air.

The fine meteoric material or micrometeorite dust will drift slowly down from meteoric heights to the weather region in about a month. Hanging in the atmosphere, these vapours mix with the colder atmospheric air and condense spontaneously into minute particles. These minute dust particles provide condensation nuclei for water and ice droplets, form clouds, and so could become instrumental in forming ice clouds (*Box* 2).

At high latitudes, meteoric dusts provide the condensation nuclei for the formation of noctilucent clouds (*Box* 3). The high velocity meteoric debris heats the upper atmosphere by friction, and generates NO_x. These particles act as one of the natural agents leading to stratospheric ozone depletion. Meteoric debris

Box 2. The Meteor Dust Hypothesis

According to the meteor-dust hypothesis, first proposed by Bowen in 1953, there exists a prospect that meteors affect the world's rainfall. In order to explain the observation that the ice nuclei are sometimes more abundant aloft than nearer the ground, that long term rainfall records show peaks on certain calendar dates, he proposed that the most effective ice nuclei in the atmosphere are particles of meteoritic dust which enters the top of the atmosphere from the outer space. The wide geographical and persistent character of these rainfall peaks led Bowen to look for an extra-terrestrial cause that would have a yearly periodicity and be active simultaneously over the whole Earth. The injection of the meteoritic particles into the atmosphere to serve as ice-forming nuclei seemed the most conceivable.

Box 3. Noctilucent Clouds

Meteoric dust plays a crucial role in the atmosphere by acting as nucleation sites for cloud growth. These are especially important in the stratosphere and mesosphere, where terrestrial dust has trouble reaching, except in cases of major volcanic eruptions. Meteoric dust is one of the most likely nucleation sites for noctilucent clouds and polar mesospheric clouds, and they may also serve as condensation nuclei for stratospheric droplets and polar stratospheric clouds that play a critical role in the destruction of the ozone layer.

Noctilucent clouds are a phenomenon generally observable only from latitudes above 45 degrees North or South, during the summer months, and the period in which the Sun is at some 5° to 8° elevation angle below the horizon. They are much higher in the atmosphere than normal clouds; they usually occur at altitudes of 85 to 90 kilometers.

These are vast fields of ice-covered particles of interplanetary origin drifting high in the atmosphere. These tiny icy particles are typically in the order of 90 nm in diameter but can attain diameters of 200 to 400 nm. The ice particles largely find their origin in vaporized meteoric material. Small meteoroids entering the Earth's atmosphere vaporize entirely. As a result of this vaporization, heavy molecules are formed, mostly heavy ions of ferro-oxides, like Fe^+, FeO^+, $FeOH^+$ and FeO_2^+. These heavy ions become nucleating agents for water-ice particles, and thus build up an icy coating and form the fields of icy particles that make up noctilucent clouds. In time these particles might react and form more complex hydrated iron molecules. Eventually, these will trickle down to the lower atmosphere and in that process lose their icy coating.

Not all micrometeoroids entering our atmosphere completely vaporize. Some survive and start to float around in the atmosphere as true meteoritic dust particles. These dust particles themselves are called interplanetary dust particles. They basically show the same structural composition as meteorites, some are chondritic in character, others are composed of nickel-iron. In time, they will trickle down to the troposphere, and then wash out with the rain to become embedded in the Earth sediments.

slowly re-condense to form dust particles, which may act as condensation nuclei for polar stratospheric clouds, and activate the chlorine-catalyzed removal of ozone. Metallic dust may also provide catalytic surfaces for reactions such as $O + H_2$ to form water.

The Atmospheric Meteors

World Meteorological Organization distinguishes its own domain of cataloguing to avoid the confusion with the meaning given to it in astronomy. As defined in the *International Cloud*

Atlas 'atmospheric meteor' refers to 'any phenomenon, other than a cloud, observed in the atmosphere or on the surface of the Earth, which consists of a precipitation, a suspension or a deposit of aqueous or non-aqueous liquid or solid particles, or a phenomenon of the nature of an optical or electrical manifestations'.

Features of the weather, such as rain, snow and hail provide ample evidence that water droplets and ice crystals occur in the atmosphere in forms other than those of clouds. Liquid and solid particles may be suspended in the air, or fall towards the Earth's surface. Sometimes they may be blown in the atmosphere by the action of the wind. On other occasions, water droplets or ice crystals may be deposited on objects on the ground or in the free air. Thus, by considering the physical processes involved in their occurrence we can distinguish four main types: hydrometeor, lithometeors, photometeors and electrometeors.

A 'hydrometeor' is a generic term for products of condensation and precipitation of atmospheric water vapour. It includes ensembles of falling particles which may either reach the Earth's surface (rain, snow, etc.) or evaporate during their fall; ensembles of particles suspended in the air (cloud, fog, etc.); particles lifted from the Earth's surface (drifting or blowing snow, spray); particles deposited on the Earth or on exposed objects (dew, hoarfrost, etc.). Generally speaking it includes water in various forms such as rain, snow, hail, dew, frost, waterspout, etc. since the physical processes behind the formation of hydrometeors are responsible for most of the dynamic phenomena observed in nature these are elaborated further in *Box* 4.

'Lithometeors' consists of ensembles of particles, most of that are solid and non-aqueous. They are the wind-driven particles found in the lowest layers of the atmosphere when snow, ice needles, ocean wave spray, dust, sand, etc. are blown by strong winds and carried to varying distances. Such solid particles

Suggested Reading

[1] D H Mc Intosh, Ed. *Meteorological Glossary*, Her Majesty's Stationery Office, 1972.

[2] J K Beatty, and A Chaikin, *The New Solar System*, Massachusetts: Sky Publishing, 3rd Edition, 1990.

[3] *Encyclopaedia Britannica*, Vol. 15, Encyclopaedia Britannica Inc., pp.268, 1971.

[4] *International Cloud Atlas*, Vol. 1, WMO, pp. 61, 1956.

[5] *KHAGOL*, No. 35, July 1998.

[6] P Maran Stephen, *The Astronomy and Astrophysics Encyclopaedia*, New York: Van Nostrand Reinhold, pp. 430-445, 1992.

[7] S Petterssen, *Introduction to Meteorology*, Mc Graw-Hill, Vol. 1 and Vol. 2, 1969.

[8] Seeds, A Michael, *Horizons*, Belmont, California: Wadsworth, 1995.

[9] J T Wasson, *Meteorites*, Springer-Verlag, New York, 1974.

[10] Alain Giraud and Michel Petit, Ionospheric Techniques and Phenomena, D Reidal Publishing Company, 1978.

[11] Herbert Riehl, *Introduction to the Atmosphere*, Mc Graw-Hill Book Company, 1972.

[12] R Hans, Pruppacher and James D Klett, *Microphysics of Clouds and Precipitation*, Kluwer Academic Press.

[13] Joel S Levine (Ed.) , *The Photochemistry of Atmosphere*, Academic Press, Inc. 1985.

[14] Mason, *The Physics of Clouds*, 2nd Edition, Clarendron Press, London.

[15] S Twomey, *Atmospheric Aerosols*, Elsevier Scientific Publishing Company, 1977.

Box 4. Brief Description on the Physical Processes Contributing Hydrometeors.

If the temperature of a parcel of air, which is under consideration, is warmer than its dew point, the air is unsaturated. Unless water vapour is added to the air, condensation will not begin until the air is cooled to the dew point temperature. As unsaturated air is cooled, its specific humidity remains constant, but its saturation specific humidity decreases. Thus its relative humidity increases. If the cooling continues until the air temperature falls to 7° C, the relative humidity reaches 100%. The air is now saturated. If the air is cooled below 7° C, condensation occurs.

In the atmosphere, condensation will not occur when the relative humidity reaches 100% unless there are some microscopic impurities present around which the water molecules can cluster. These condensation nuclei come from a variety of sources such as sea salt particles produced by the evaporation of ocean spray, products of combustion, extra terrestrial dust particles, and dust swept from the land by the wind. The continual mixing of the atmosphere carries these nuclei throughout the atmosphere. The particle concentration is usually greatest near the source. Water molecules start collecting on them even before the humidity reaches 100%.

Relatively warm, moist air moving over a colder surface, the mixing of warm, moist unsaturated air with colder unsaturated air; the radiative cooling from the land surface, and upward motion of air initiate the cooling required to produce condensation. The latter two processes are the most prominent in producing condensation, the last being essential for the formation of precipitation.

Precipitation is the general term used to denote the fall of liquid water drops or ice crystals from the clouds to the ground and hence covers drizzle, rain, shower, snow and hail.

In a growing cloud some ice crystals may form along with the liquid cloud droplets. It is the type of condensation nuclei that determine whether an ice crystal or a water droplet will form. Some ice crystals form directly around freezing nuclei, the determinant of ice crystal formation, while other ice crystals form when super cooled liquid cloud droplets collide with freezing nuclei. Consequently at temperatures below zero degree C and at a favourable vapour pressure, the air may be slightly unsaturated w.r.t a water surface but slightly supersaturated w.r.t an ice surface. Thus the vapour pressure gradient is directed from the water surface to the air and from the air to the ice surface. As a result the coexistence of ice crystals and liquid droplets represents an unstable situation, since the liquid droplets tend to evaporate, while the ice crystals become larger. This is the beginning of the precipitation process.

The growth of ice crystals eventually leads to a cloud composed of a mixture of growing ice crystals and small cloud droplets. As the ice crystals become sufficiently large, they begin to fall relative to the cloud droplets as precipitation.

lifted from the Earth's surface by wind and suspended in the air are termed lithometeors.

References from these websites are used to illustrate *Figure* 1

http://www.solarviews.com/cap/meteor/chndrite.htm
http://www.solarviews.com/cap/meteor/achndrit.htm
http://www.solarviews.com/cap/meteor/iron.htm

Other useful website:
http://www.imo.net

A 'photometeor' is also a generic term. Clouds in the atmosphere may be composed of water droplets, ice crystals or a combination of both. If the clouds are thin enough to permit the Sun or the Moon to shine through, they produce various effects. These phenomena occur when light from the Sun or the Moon is either refracted or diffracted by the ice crystals or water droplets. Examples include halo, corona and rainbow. Halo is the result of the refraction of the rays by the hexagonally shaped ice crystals whereas the latter two are the result of diffraction of light rays by the spherically shaped water droplets.

'Electrometeors' are the manifestations of atmospheric electricity in various visible or audible forms. These manifestations can either be as discontinuous electrical discharges, as in the case of lightning and thunder or continuous such as St.Elmo's Fire or aurorae.

Conclusion

The meteor phenomena is interesting mainly because they carry information about a wide variety of processes, such as, those which occurred in planet-like bodies, and which were similar to processes occuring in the interior of the Earth and the other planets; those resulting from collision between interplanetary objects and those produced by interaction with solar and galactic cosmic rays. From the viewpoint of considering the meteorite as fragments of a broken planet, one is expected to learn, and in all probability has learnt about the interior of the Earth, such as the existence of an iron core of a manganese rich mantle. The myriad expression of the physical processes of the non-astronomical meteors in the Earth's atmosphere offers numerous possibilities to appreciate Nature's intricate manifestations. Some useful references are given in Suggested Reading. To know more about astronomical meteors, one may visit the official website of International Meteor Observation (http://www.imo.net) and for atmospheric meteors, the World Meteorological Organisation (http://www.wmo.org).

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