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The Moon and the Opposition Effect

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Abstract: During Full-Moon the moon and the sun are in opposition configuration toward an observer on earth, and the moon brightness is maximal. The brightness drops rapidly when the bodies deviate from the opposing geometry a day before or after the full moon. A similar phenomenon is observed in other bodies with light that is scattered from the solid surfaces, but not from gaseous surfaces. The enhancement of the full-moon brightness, in the opposition state, is the direct outcome of single light scattering. There is no need for further models to discuss this phenomenon.

During Full-Moon the moon is in front of an observer on earth and the sun is behind it, so that the three bodies are located nearly along a line, with a little shift to avoid hiding the moon from the sun by the earth. In this opposition configuration sun light hits the moon and is scattered nearly 180 degrees back to an observer on the earth, and the moon brightness becomes maximal. It drops rapidly when the sun is shifted sideway by a few degrees[1]. This opposition effect is observed also with other celestial objects, and with similar terrestrial systems as well[2].

When an electromagnetic wave advances in a medium it polarizes its matter, and each polarized dipole of the matter becomes a source of electromagnetic wave. The effect of all the dipoles is calculated, for example, by vector addition of their electric fields. Each dipole has a different phase that depends on its position, and if the material is uniform the dipole fields cancel each other in all the directions in space except the forward direction, where the effect is refraction.

Scattering comes from non-uniform fluctuations of material density, and then scattered waves may advance in any direction. The intensity of scattered light is the sum of the intensities of the scattering centers and it does not depend on the phases of the scattering dipoles.

Each dipole oscillate in the electric field direction of the coming sunlight, that is, in a plane perpendicular to it, and the maximal emission of a dipole is perpendicular to its direction of oscillation, that is, back to the sun. Therefore, the mean equivalent moonlight will also be directed back to the sun, and in full moon also to an observer on the earth 3.

The function of a plane wave is ei(kr-wt), where r is the is the wave coordinate, w is the light frequency and k is the wave number. k . r is the phase. $k = 2\pi / \lambda$ where λ is the wavelength. Assume that sunlight advance in the z direction and a scattered light in the r direction, and the angle between them is θ. The phase difference between the two waves will be:

$$k \cdot r - k \cdot z = k \cdot r(1 - \cos(\theta))$$

When moving along the r direction within a scattering center, the phase will oscillate and the average scattering will diminish. There is contribution only if the phase change along the scattering center is smaller than π. The scattering distribution becomes:

$$k \cdot r(1 - \cos(\theta)) <= \pi$$

Thus, the scattering width depend on the size of the scattering center.

For small angles, Cos (θ) = 1 – 1/2 θ2, the scattering width becomes:

$$1/2 \cdot k \cdot r \cdot \theta^2 <= \pi$$

Or: $$\theta^2 <= \lambda/r$$

For example, if the scattering width is 5^o, that is $\theta = 5 \pi /180$ radian, and the wavelength is $\lambda = 0.5$ micron, then the size of the scattering center will be:

$$r = \lambda / \theta^2 = 0.5 (36/\pi)^2 = 65 \text{ micron}$$

This value is typical to scattering in solids.

If the size of the scattering center is far below the light wavelength, the width will be far higher. There will not be opposition effect, and the scattering will be practically uniform. This is Rayleigh scattering, typical to a gas phase.

The opposition effect is indeed observed in the solid surfaces of the Moon, Mars and the asteroids. It is not observed with the gas clouds that cover Venus.

The brightness enhancement of the full-moon in opposition, as of similar other bodies, is a direct outcome of single light scattering. For similar reasons, the uniformity of the full moon and other bodies of the opposition geometry, is again a direct outcome of single light scattering. A coherent back scattering model[1, 4] is mentioned for the full-moon brightness. However, there is no need of any model for dealing with these cases.

References

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Moral of the story:

The scattered light is considered in the literature as a diffusive light, light that passed a number of scattering events before it left the scattering material. Diffusely scattered light must obey Lambert's Cosine scattering law. In the case of unidirectional light scattered backward from a surface of a sphere, the meaning is maximum scattering intensity in the middle of the sphere surface, and a decline to zero toward the periphery by the cosine law.

The full moon looks uniform, people continue to assume that the light is diffusely scattered from it, and make double saltas and backward flick-flacks in order to try to explain the uniformity, in my opinion, without success.

More than that. The nearly uniform sphere image, is common to all the planets and their moons, including the earth as observed from the moon. Out of thousands upon thousands true photos, there is no single true photo that obeys Lambert's Cosine law. The only photos that do obey the law are rendered photos, photos that are at least partly simulated. Rendering: If the theory does not comply with reality we'll change the reality.

Contrary to all that, if the scattering is assumed to be mainly a single event, then all the scattering dipoles are directly stimulated by the light radiation on the illuminated scattering material. Then scattering by them must be coherent, and then the full moon and all the other illuminated bodies, with similar illumination geometry, must be uniform, at least approximately. The full moon tells us that single event scattering is dominant. Maybe with small corrections of multiple scattering.

Why is the single event dominant? It seems that the effect is geometrical and statistical. If we consider one event scattering, two event scattering, multiple event scattering, then the event probability will decline with an increasing number of scatterings. The single event has a probability of at least 50% and it is the strongest event. Assume that someone can make more accurate statistical calculation.

Nearly all the background landscape that surrounds us is a singly scattered light. A true diffusely scattered light is rather rare.

In summary, the full moon tells us how to remove undesirable incoherent stray light from coherent scattered light, for example, in optical absorbance measurements.

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