Why the sky is blue

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Abstract: The "Tyndall effect" and "Rayleigh scattering" are the accepted explanations for the blue color of the sky. However, since heavy rainfall is known to remove particulates as well as the gases and yet the sky actually becomes a deeper blue in color, both explanations are probably invalid. The current author proposes the following explanation for the blue color of the sky: This is the pale blue of ozone gas, which will appear deeper blue when there are sufficient quantities of it. Further, ozone attains an even deeper blue color when it becomes a liquid at around a temperature of 161 K (-112 °C) and a blue to violet-black solid at temperatures below 82 K (-193.2 °C). The latter is the case in the lower Stratosphere, especially near the poles. Also, since ozone absorbs ultraviolet radiations, it is likely that some of the spectra close to UV (such as violet, indigo, and blue) radiations are also absorbed or scattered by ozone and this may add to the blue color of the ozone layer. To an observer on the surface of the earth, the many layers of dust and other particulates in the intervening Troposphere, which dampen the deep blue of the ozone layer, will make the "sky" appear less blue. How much each of the above factors contributes to the color of the sky is not known but jointly, they can explain all the observed phenomena. © *2017 Physics Essays Publication*. [http://dx.doi.org/10.4006/0836-1398-30.1.116]

Résumé : L'effet Tyndall et la diffusion de Rayleigh sont les explications admises de la couleur bleue du ciel. Les fortes pluies sont cependant connues pour éliminer les matières particulaires ainsi que les gaz tout en donnant au ciel une couleur bleue plus foncée, ce qui signifie que ces deux explications sont probablement incorrectes. L'auteur de cette étude propose l'explication suivante pour la couleur bleue du ciel: il s'agit du bleu pâle de l'ozone gazeux, qui apparaît plus foncé lorsqu'il est présent en quantités suffisantes. En outre, l'ozone acquiert une couleur bleue encore plus foncée lorsqu'il devient liquide au voisinage de la température de 161 K (−112 C), et une couleur entre le bleu et le violet-noir lorsqu'il devient solide à moins de 82 K (−193,2 C). Cette dernière situation existe dans la stratosphère inférieure, en particulier près des pôles. Sachant que l'ozone absorbe le rayonnement ultraviolet, il est probable qu'une partie du spectre au voisinage du rayonnement UV (notamment le violet, l'indigo et le bleu) est aussi absorbé ou diffusé par l'ozone, ce qui accentuerait la couleur bleue de la couche d'ozone. Pour un observateur à la surface de la terre, les nombreuses couches de poussières et autres matières particulaires dans la troposphère (qui occupe une position intermédiaire) atténuent le bleu foncé de la couche d'ozone et donnent une apparence moins bleue au « ciel ». La contribution de chacun des facteurs ci-dessus à la couleur du ciel n'est pas connue, mais ensemble ils peuvent expliquer tous les phénomènes observés.

Key words: Tyndall Effect; Rayleigh Scattering; Ozone; Stratosphere.

I. INTRODUCTION

The blue color of the sky was originally attributed by scientists to the Tyndall effect. Described by John Tyndall in 1859, this effect is a preferential scattering of shorter wavelength blue light by particulate matter (particles 40–900 nm in size, the wavelength of visible light being 400–750 nm) in the atmosphere.[1–3] The longer wavelength spectra of sun's light such as red and yellow have the ability to course through these particles. Thus, while we see sky as being blue, the sun and the sunlight take on a yellow hue. A classic example of this phenomenon is the bluish tinge assumed by an opalescent stone when a beam of white light traverses the stone, while the light that exits on the opposite side takes on a yellowish tinge. Experiments to prove the above explanation involved passing light through containers of water with a suspension of colloidal substances; milk has been a popular ingredient in these experiments. The demonstration that the container turns bluish in color, while the beam of light that exits the container is more yellow/red has been quoted as confirming the phenomenon and as the explanation of the color of sky. The scientific explanation of related observations such as why near the horizon the sky appears less blue and at dawn and dusk the sun and the sky appear orange-red is also attributed to the same scattering effect. In the former, more scattering of blue light by the increased amount of particles in the air closer to the earth is given as the reason. The latter effect is attributed to "rescattering" of blue light so that the orange and red are accentuated.

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The Tyndall effect was discarded later as scientists could not explain why the sky does not appear bluer by the increased amounts of water vapor and dust in rainy conditions. And, after the sky is cleared of dust and particles, the sky does appear bluer, not less. Further study by Lord Rayleigh discovered that the amount of light scattered was inversely proportional to the fourth power of the wavelength of light, for finer particles (particle size below 40 nm).[4,5] Based on these studies, the current explanation is that the scattering of blue light is due to the oxygen and nitrogen in the air, rather than the particulate matter. Thus, the shorter wavelength blue light is scattered by these molecules, whereas the longer wavelength yellow and red pass through relatively unaffected. Larger particles in the atmosphere such as water vapor are credited with scattering of light of all wavelengths and this is called Mie scattering, named after the German Physicist Gustav Mie.[6] Due to this scattering of light of all wavelengths, the clouds at sunset appear gray/white while the rest of the sky appears yellow-red due to Rayleigh scattering.

This paper proposes that the colors associated with the sky at different locations, at different times of the day and in different weather conditions are due to very different phenomena. In the subsequent paragraphs, we will explain how the color of ozone in the ozone layer imparts different hues of blue, depending on the location, the ambient temperature, prevailing weather conditions, etc. When appropriate, we will also assign appropriate role for actual "removal" of shorter wavelength light by dust/particles in the atmosphere.

II. DISCUSSION

In preparation for this paper, a thorough review of the scientific literature available both in print and online was made. What was discovered was that most authors narrate a confused array of explanations and they could not satisfactorily explain all the observed phenomena and in all circumstances. Their attempts to explain the varied phenomena such as the usual blue of the sky, the lighter blue of the horizon, the multicolored sunsets and the blue haze of distant objects, all being attributable to Rayleigh scattering or Tyndall effect can be questioned. We will discuss below why their explanations fail in some situations and why the inclusion of the ideas expressed in this paper more completely explains the observations.

This author had long been skeptical about using the scattering of blue radiations by the particulates or molecules as the explanation of why the sky is blue. If blue light is preferentially "scattered" by the molecules (or particulates), then more molecules closer to the earth at horizon should make the sky appear deeper blue, not less. And, if the blue color is scattered all through the atmosphere, then the clouds should appear blue and not white, as we are looking at the clouds through layers of the atmosphere. The dusty atmosphere of Mars makes its sky appear red in the usual conditions; this has been attributed to the high concentration of iron oxide in its atmosphere.[7] Images of Martian sky sporting a pale blue color when the dust settles down has been noted, and reports of not only the presence of ozone in its atmosphere but also at least two layers of it have been presented.[8,9] In the case of the earth's moon, the atmosphere is black but its atmosphere is not devoid of gases and particulate matter; it has significant quantities of dust, Helium, Neon, and Hydrogen.[10] However, it is unknown if the amount of dust and the gases are inadequate to produce Rayleigh's scattering and that is why the sky on the moon is black. The absence of ozone in moon's atmosphere is noteworthy, however and this, we believe, is the real reason for the absence of blue color in moon's sky. Our review of NASA's website did not reveal the presence of a blue sky in any of the other terrestrial planets. Ozone is conspicuously absent in all their atmospheres, unlike in the earth's and Mars'.

Ozone is situated in a region of the atmosphere in the middle part of the Stratosphere, between 10 and 50 km, like an envelope around the earth. This layer of ozone can impart a blue color in at least two ways. First, the natural color of ozone gas is a light blue; one could argue that a column of such gas or innumerable layers of the gas when viewed as a whole might appear even bluer. Also, the ambient temperature in the Stratosphere is cold enough so that some of this ozone may turn into a liquid and hence impart a deeper blue hue.[11–13] It is also known that the pale blue color of ozone gas turns to a deep blue black when it becomes solid at even lower temperatures. Thus, the ozone layer of the Stratosphere will appear blue of different degrees, depending on the prevailing temperature in each region, including a deep blue-black in the poles.

Ozone may impart a blue color to the Stratosphere in another way. Ozone absorbs the harmful UV radiations from sunlight. Since the UV spectrum is very close to the violet, indigo, and blue spectra, the aggregate might be a hue of blue. This may be because quantitatively the blue light dominates or because the aggregate of blue, indigo, and violet is still registered as blue by the cones (the color-sensitive photoreceptor cells in the retina that decipher color, and which are most sensitive to red, green, and blue colors). How much of this particular effect contributes to the overall blue color of the ozone layer, or whether other physical phenomena in the Stratospheric region, such as the very low gravitational effect from the earth is also important, is not known.

It is proposed that this ozone layer, which exists literally as a globe around the earth, with its trapped blue color is the reason for the illusion that the sky is blue in color. This will then explain why in cloudy conditions the color gets less intense and after a heavy rain has cleared the atmosphere of particulate matter, including dust, and even substantial amounts of the gases, the sky appears deeper blue. Numerous scientific studies have provided evidence of clearance of particulates by the process of "impaction" by raindrops, as well as by gravity and, of the gases by a process called "scavenging."[14–22] This clearance of the particulates and gases by rain deepening the blue color of the sky will make the Tyndall Effect and Rayleigh's scattering untenable as explanations for the blue color of the sky. The above also suggests that in normal circumstances, the pale blue color of the sky is due to some dampening effect from the light traversing the particulate matter in the earth's atmosphere. This hypothesis further explains why the clouds, which are much closer to an observer on the surface of the earth, in the Troposphere, than the ozone layer, (which is in the Stratosphere) therefore do not take on the color of the sky. The above two observations also cannot be explained by either the Tyndall or Rayleigh scatterings. When viewed from the space (beyond the Stratosphere), for example, from the space shuttle, the earth has a deep blue color; this is because the observer is viewing the proper color of the ozone layer, without the diluting effect of the earth's atmosphere. The haziness near the horizon when the sun is overhead, like during the midday, is also easy to explain by the current hypothesis; the increased dust close to the surface of the earth obscures the color of the sky to a greater extent than the sky overhead, when the line of the observer's view is perpendicular to the sun's rays.

Similar explanations will account for the deep blue color of sky in pristine locations in nature (such as the forests) and increasingly lighter blue to gray shades in dusty locations. The orange-red appearance of sunsets and sunrises is due to the Sun's rays traversing through the thick layers of dust close to the earth, and in the process the dust particles progressively allowing the longer-wavelength rays such as yellow and red preferentially to pass; the present author is in agreement with the conventional explanation, only in this phenomenon. It is also worth noting that the orange/red color imparted by this phenomenon paints the clouds and the intervening sky, as well as the sun, unlike the blue color residing only in the sky during the rest of the daylight hours. A related phenomenon is how the moon takes on a red tinge just before the total eclipse of the moon; here the sunlight skimming the layers of dust close to the earth before reaching the moon is filtering out the shorter-wavelength blues.

The finding of large areas of deeper blue in the Polar Regions has been ascribed to loss of ozone ("ozone hole"). The current author believes this to be an erroneous assumption. While it is true there is loss of ozone, presumably from the use of Chlorofluorocarbons (CFCs), that will not increase the blue color of the sky in any region. Besides, even reductions in the ozone from aerosols will be near the landmass of the earth in areas other than the poles, and particularly in regions with heavy human habitation. The poles have few if any human activity and it is more likely the atmosphere there is pristine. Instead, since the temperatures around the Poles are much lower than elsewhere, it is much more likely that even if there were diminished amounts of ozone in those regions, it will still appear to be a deeper blue in color, simply because the ozone is partly in a liquid or even a solid state. There are reports of increases in ozone in the Polar Regions in the spring and this has been attributed to "ozone-rich air rushing" in from lower latitudes.[23] One could instead argue that the lower ozone gas measured at the poles in the winter may be due to the inability of the currently available methods to measure liquefied or solidified ozone in the

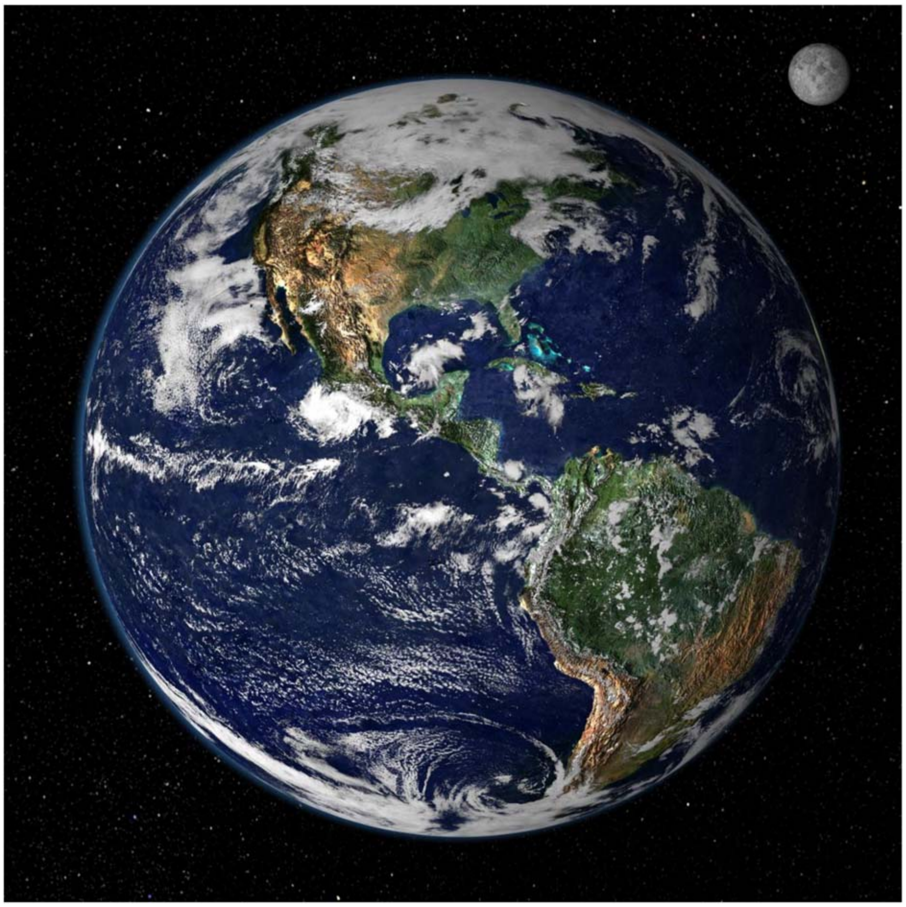

FIG. 1. (Color online) View of the Earth from the space. This is an image of the earth and moon from the outer space. Note the deep blue color of the globe. Also, there is a clear strip of blue envelope around the globe, clearly visible on the left edge of the image of the earth, with a sharply delineated edge. The black color outside the earth is the deep space, and the moon is the small gray ball near the right top corner. This image is from www.nasa.gov/multimedia/imagegallergy/index.html

intense cold of the winter. The increases in ozone in the spring in these regions may simply be the warmer temperature converting some of the liquid or solid ozone to the gaseous form and thus becoming measurable.

Proof for the current explanation of why the sky is blue can be found in the fact that astronauts in space shuttles notice a completely black sky, whereas travelers in the commercial aircrafts, which fly in the Stratosphere see the sky as deep blue in color. The ozone layer is in the Stratosphere level (approximately 10–50 km above the earth), whereas the space shuttles and most of the satellites travel or are situated around 300–400 km range above the surface of the earth, in the Mesosphere. Even more suggestive is the appearance of the earth itself from outer space; there is a strip of deep blue color extending from the surface of the earth to a short distance, all around the globe. This blue color abruptly ends with a sharp edge as if enclosed within an envelope. This can be used as the most compelling argument in favor of the blue color of sky residing primarily in the ozone layer. If, on the other hand, the blue of sky is solely due to scattering by molecules close to the earth, the diminishing quantities of these same molecules farther and farther out from the surface of the earth should produce the appearance of gradually diminishing blue, rather than an abrupt cut-off (Fig. 1).

If human activities manage to destroy all ozone around the earth, we will then probably see the sky as being black as well, here on earth. Experiments to prove (or disprove) our current explanation might be difficult, if the extremely low temperatures, low gravity, and the rarefied air, as well as a certain concentration of ozone are critical for the blue color display. Obviously, such experiments can only be arranged in the outer space, to reproduce the low gravitational state, if that is also critical. If the color is reproduced by such experiments, removing the ozone from the system and demonstrating that the blue color is lost, will clinch the proof.

III. CONCLUSION

This paper presents arguments about the contributions made by ozone in the ozone layer surrounding the earth, to the blue color of the sky. The current author suggests that the blue of the overhead sky is due to the color of ozone, while the haze in the horizon is due to increased dust close to the surface of the earth, physically obstructing the blue of the ozone. The orange-red of the sunsets and sunrises are due to preferential passage of the longer wavelength yellow and red by the same dust but while the sun's rays are traveling parallel to the earth's surface and in the line of an observer's view. This article thus emphasizes that different phenomena surrounding the sky and the atmosphere have different physical bases, rather than only one is offered to explain all the varied observations.

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