European Journal of Applied Sciences – Vol. 10, No. 1
Publication Date: February 25, 2022
DOI:10.14738/aivp.101.11643.
Raghuprasad, P. K. (2022). Why the Sky is Blue: The Ozone Connection Revisited. European Journal of Applied Sciences, 10(1). 260-269.

SOCIETY FOR SCIENCE AND EDUCATION

Why the Sky is Blue: The Ozone Connection Revisited

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ABSTRACT

Blue sky is a feature on earth and Mars, the only planets in our solar system with well-defined layer(s) of ozone in their atmospheres. After heavy rains remove most of the dust and varying amounts of gases, the earth's sky appears deeper blue; this argues against Rayleigh's scattering as being responsible for the blue color of sky. Also, in this paper we make the argument that since at least 50% of earth's atmospheric molecules are held close to the surface of the earth, in the lower 6 km or so, Rayleigh scattering should make the sky closer to the earth appear deeper blue and the overhead sky lighter; in fact, the reverse is true. We also believe that scattering of blues in all directions should make the clouds and the objects close to the ground also to take on the blue color; instead, what we see is white clouds floating in front of a uniform background of blue and no increase in blue tinge in the structures close to the earth's surface. In contrast, the true splitting of setting sun's rays makes the light and the sky to take on an orange-red color, but in this setting the clouds and objects in the rays' path also appear yellow-orange, as one would expect. The absence of blue sky in other planets' and our moon's skies despite having varying mixtures of gases but no defined ozone layer, and the black "sky" beyond the lower parts of the earth's atmosphere beyond the stratosphere, and particularly the appearance of a sharp demarcation about the lower part of the stratosphere where the blue stops and black sky appears, all argue in favor of ozone as being responsible for the blue color of sky. We propose in this paper that the proper color of sky is dark blue, as seen in pristine locations and in photographs of the earth from space, but the sky over cities and other dusty places becomes lighter blue; the almost white color of sky at horizon is due to the density of dust in the atmosphere closest to the ground.

Keywords: Blue photons, Ozone, Rayleigh Scattering, Stratosphere, Tropopause, Troposphere

INTRODUCTION

Rayleigh's scattering has been the accepted explanation of why the sky appears blue during the day (1). The theory is that when midday sunlight traverses the troposphere, the air molecules scatter the shorter wavelength blue photons, while allowing the longer wavelength yellow and red photons to pass through to the ground. The same phenomenon that imparts blue color to the daytime sky has been used to explain how the sunrises and sunsets appear orange red. In a prior paper (2),

we explained how instead of the above, the ozone layer in the stratosphere, might alone explain the blue color of the sky, the layers of dust in the lower troposphere partially "diluting" the blue of the ozone gas. We proposed that a primary way in which ozone contributes to the blue color may simply be by its existence in a defined layer, and simply the thickness of this layer making the pale blue gas appear deeper blue. Also, we wondered if some of the short wavelength blue photons are absorbed along with the ultraviolet and displayed by the ozone layer, which then accentuates the blue of the layer. We speculated that some of the ozone in the ozone layer might even be deeper blue due to becoming liquefied, in that area of the stratosphere with the markedly diminished gravity, especially in the sky at the poles. Thus, both the sky as it appears to observers on the surface of the earth, as well as the appearance of the earth from outer space, we proposed were due to the ozone. We also observed that the blue-black to black of the sky over the poles were likely due to the even lower temperatures prevailing at the poles, especially during winter months making the ozone gas actually becoming crystallized to blue-black solid. We suspect that it does so, even though the ambient temperature is not low enough for ozone to liquefy or crystallize on earth, but in the extremely rarefied state due to reduced gravity, in the tropopause where ozone layer is situated, such changes in the physical state of ozone may actually take place. This was offered as the true explanation, rather than a purported "hole" left by loss of ozone due to the use of chlorofluorocarbons in aerosol cans. We argued that any such depletion of ozone due to the aerosols would be over the landmasses where people live, especially over the industrialized countries and not in the poles where there are no human inhabitants. We had also offered some other phenomena to support the role of ozone in the color of the sky. Such were the presence of blue sky only on earth and Mars, the only planets with a layer or layers of ozone in their atmospheres. We also made the argument that after most of the dust and varying amounts of the atmosphere's constituent gases were removed by heavy rainfall, the intensification of the blue color of sky actually supports our notion that the color of the ozone layer is why the sky is blue.

MATERIALS AND OBSERVATIONS

A search of the NASA's website (3) and the current scientific literature (4-6) yielded data pertaining to the types of gases and molecules present in the different layers of the atmosphere on earth, as well as on those of the other planets in the solar system. Such information is useful in determining the roles played by the gases in imparting color to the sky. Some of the discoveries of such searches have been presented in our previous paper (2); the current paper has included them for the sake of completion, and some are illustrated in figures and tables. The discovery that not only the sky on Mars is blue, but there are two or more distinct layers of ozone on its atmosphere, was uniquely useful, as the earth and Mars are the only two planets with both ozone layer(s) and blue skies. We will describe below in detail those and other observations that argue in favor of our assessment that ozone alone can explain all the findings in relation to the color of the sky on earth in various situations and places:

1) The appearance of the sky near the horizon and the color of the clouds and objects on/near the ground. It is common experience that the sky near the horizon is either lighter blue or even almost white in most urban locations. This is contrary to what one would expect, if the blue color of sky is due to blue photons scattering. If such scattering is due to the gases in the atmosphere, the tighter packed molecules nearer the surface of the earth should produce deeper blue than the sky overhead. The clouds are white in color in midday sky (except for the rain clouds). We present two figures below to illustrate what our normal experience with the color of sky is and that of the clouds and structures in the scenery, and contrast those with what we expect to see if Rayleigh scattering is the reason for the blue color of sky.

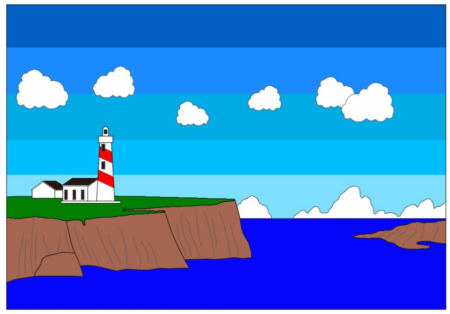

Fig. 1a

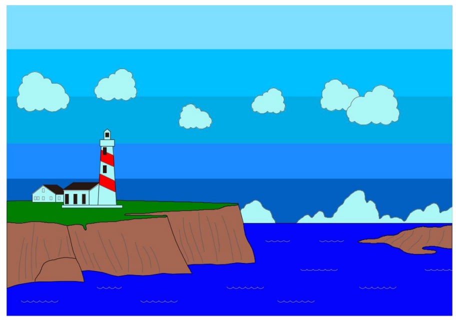

Fig. 1b

The figures above are schematic representations of the appearances of the sky, as well as all structures on the ground as they appear to us (Fig. 1a), and as they would appear if the blue photons are selectively scattered by the molecules in the air, as is proposed by Rayleigh scattering theory (Fig. 1b). Notice the deeper blue of sky in the zenith and lighter and lighter shades as one shifts one's gaze to the horizon, in Fig.1a. Notice also the clouds are white and the rest of the scenery are as we usually observe. The image in Figure 1b is the same scenery but modified to demonstrate how one would expect the same sky, clouds and the objects and structures would appear if scattering of blues is how the sky attains its blue color. In Fig. 1b, the sky has deeper hue near the horizon and lighter shades as one approaches the zenith; likewise, the clouds and all structures close to the ground also have some blue tinge. Of course, in these highly schematic representations, the different shades of the color of sky are sharply demarcated. However, in real life the gradations will be gradual; how much of blue is displayed by clouds, the horizon or the structures on the ground are, of course conjectural. These figures are just, meant to represent and convey the idea.

2)Fifty percent of the total mass of the atmosphere is in the lowest 5.6km of the Troposphere (3-7). Figure 2 below shows a schematic representation of the strata of earth's atmosphere on the left margin, with the percent distribution of the molecules of air in the different parts of the atmosphere. The latter shows that 50% of the air molecules are held close to the surface of the earth, in the closest 5.6km of the Troposphere, and 90% are held in the lower 16km of Troposphere. Even in this diagram, which is not to scale, it is obvious that the rest of the earth's atmosphere, comprised of the vast majority of space around earth, from Exosphere, through Thermosphere, Mesosphere and Stratosphere only contain 10% of earth's atmospheric gases and molecules.

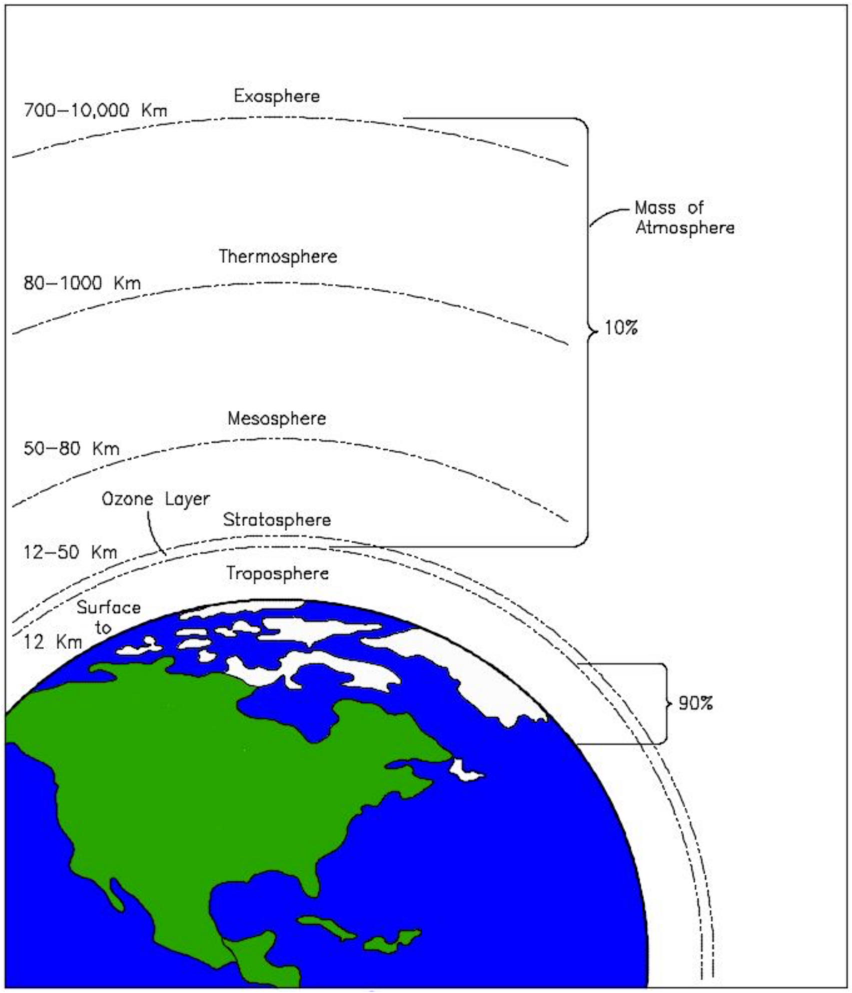

Figure 2

3)"Ozone holes" in the poles:

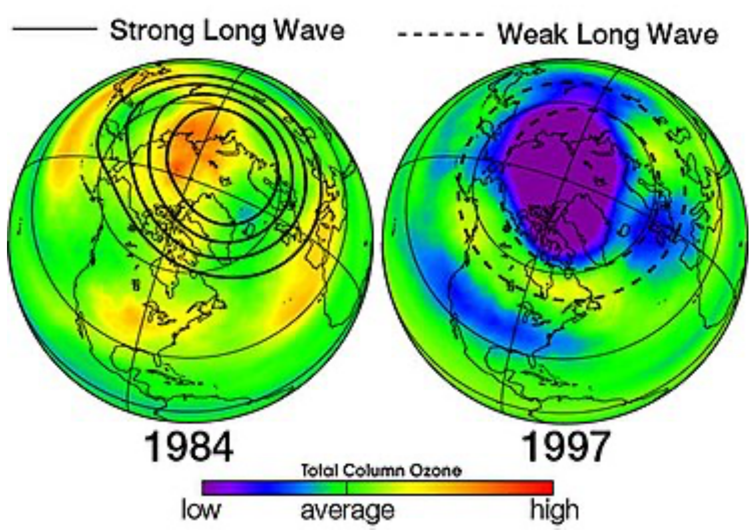

Figure 3

Ozone hole in North America during 1984 (abnormally warm, reducing ozone depletion) and 1997 (abnormally cold, resulting in increased seasonal depletion). Source: NASA[35]

The image of North pole on the left shows the appearance of the earth from outer space in the winter of 1984 and that from 1997 on the right. The 1984 picture shows a more or less uniform greenish yellow of the globe but the one from winter of 1997 has a large area near the pole and a couple of "satellite", smaller areas showing deep blue/violet color. The legend below this figure reads "Ozone hole in North America during 1984 (abnormally warm, reducing ozone depletion) and 1997 (abnormally cold, resulting in increased seasonal depletion)." We explain the conspicuous differences this way: the picture in 1984 probably shows the polar atmosphere as showing the color of ozone gas, whereas the "abnormally cold" atmosphere in 1997 probably resulted in some of the ozone gas to liquefy or crystallize and show up in deeper violet blue color.

4)The sky is blue on only earth and Mars; these are also the only planets in the solar system with distinct ozone layer(s) (7-10). Further, the atmospheres of all other planets have gases and elements in varying proportions (Table I, below). If Rayleigh scattering is due to any gas in the atmosphere, clearly, the atmospheres of some of the other planets also should appear bluish in color.

TABLE I: ATMOSPHERES OF PLANETS

PLANET	TOTAL MASS (10^{24}kg)	CONSTITUENTS MAJOR (PERCENTAGE)								MINOR (PPM)	TRACE
		N_2	O_2	H_2	CO_2	CH_4	Na	H_e	Other		
MERCURY	0.330	t	42	22	t		29	6		K 0.5%	A_r, CO_2, H_2O, X_e, K_r, N_e, C_a, M_g
VENUS	4.89	3.5			96.5					SO_2, 150, A_r 70, CO 17, H_e 12, N_e 7	
EARTH	5.97	78	21							A_r 9340, CO_2 380, N_e 18, H_e 18, H_e 5.2, CH_4 1.7, K_r 1.1 H_2 0.55	
MARS	0.64	2.7	0.13		95.3				A_r 1.6 C_0 0.08	H_2O 210, NO 100, N_a 2.5, K_r 0.3, X_e 0.08, HDO 0.05	
JUPITER	1,898			90.97				8.89		O 774, C 330, N_e 112, N_2 102, F_e 43, M_g 35, S_i 32, S 15	
SATURN	568			96.3				3.25		CH_4 4500, NH_3 ____ HD 110, Ethane 7	
URANUS	86.8			82.5		2.3		15.2		HD 148	
NEPTUNE	102			80		1.5		19		HD 192, C_2H_4 1.5	

A_r = Argon, C= Carbon, C_2H_4= Ethane, CO= Carbon Monoxide, CO_2= Carbon Dioxide, CH_4= Methane,
F_e= Iron, H_2= Hydrogen, H2O= Water, HD= Hydrogen Deuteride, HDO= Hydrogen Oxygen Deuteride, H_e= Helium, K_r= Krypton, M_g= Magnesium, N_2= Nitrogen, N_a=Sodium, Ne= Neon, NH_3= Ammonia, NO= Nitrous Oxide, O_2= Oxygen, ppm= parts per million, S= Sulfur, S_i= Silicone, SO_2= Sulfur Dioxide, t= trace amounts, X_e= Xenon
Source: nasa.gov

5) The common experience of the sky appearing deeper blue in color after heavy rains cannot be explained by Rayleigh scattering as most of the dust particles and substantial amounts of atmospheric gases are removed from the air (11-19). On the other hand, such clearance of particulates from the air exposing the true color of the ozone layer adequately explains this phenomenon.

DISCUSSION

The daytime sky on earth is a shade of blue of varying degrees, with the appearance of blue being the background color, and clouds floating against that background. The clouds take on different colors depending on the type of the cloud and the time of day, and they are constantly in motion against the prevailing background color of sky. In this paper, we ask the question, if the blue color of sky is due to scattering of short wavelength blue photons by atmospheric gases, shouldn't all objects in the atmosphere take on that color, including the clouds? Also, as 50% of the gases and particulates in the earth's atmosphere are held close to the surface of the earth by its gravity in the lower 5.6km of the troposphere, by Rayleigh scattering the deepest blue color should be close to the earth and make the horizon to appear deepest blue. In reality, the exact opposite is seen; the deepest blues are at the top (overhead) and the lightest or almost white parts of the sky are at the horizon. Dust held in the atmosphere closest to the surface of the earth obscuring the background color of the sky from ozone layer can explains this finding.

There is unanimous agreement about the orange red of sunrises and sunsets as being due to sun's rays traversing parallel to the earth's surface, through layers of dust and in that process losing the short wavelength blue photons. We are in total agreement with this explanation; the appearance of the sky during the midday is a distinctly different phenomenon. When large amounts of dust and particulates are present in the lower atmosphere, the deep blue color of sky gets tempered by them and the blue gets lighter. It is interesting to note that the orange red of the sky at sunrises and sunsets are also imparted to the clouds, as the altered light from the rising and setting sun also fall upon them. We believe that by the same effect, daytime scattering of blues should affect the color of clouds, thus rendering them also blue. But that is not what we see. Also, sunsets after heavy rainfalls make both the sky and clouds much lighter yellow or almost white; evidently, the clearing of dust from the lower atmosphere is responsible for this effect. The exact same explanation can be put forward for the reddish appearance of moon just before the lunar eclipses; sunlight filtering through layers of air close to the earth's atmosphere accounts for the red color. It is not surprising that the background deep blue of the sky returns near the horizon after heavy rainfall. Similarly, the overhead sky becomes deeper blue, as the reduction of the dust in the lower layers of the troposphere removed the partial obscuring of the blue of the sky.

In our previous paper (2), we made the observation that the only planets in our solar system with blue sky are the earth and Mars. These are also the only two planets with distinct layer(s) of ozone around them (7-10). In this paper, we provide data on the types and quantities of gases and elements in the respective atmospheres of the other planets. We are making the point and asking the question that, if Rayleigh scattering were responsible for the color of the earth's sky, why some of these planets also do not sport blue sky, as they also have substantial amounts of gases and elements in their respective atmospheres. Since Mars does have blue sky and it has two or more distinct layers of ozone, it is another argument that it is the ozone in the atmosphere in a well-defined layer(s) that leads to the blue color of the sky.

For decades, the scientific community had been concerned about the effects of the propellants in aerosols (chlorofluorocarbons or CFCs) interacting with the ozone in the ozone layer and depleting it, which would then lead to many ill-effects from the unchecked flow of UV light on the earth's inhabitants (20-25). Two pieces of evidence have been offered by scientists for this concern: First, the observation of large dark areas in the poles, which have been called "Ozone holes". Second, the demonstration of reduced amounts of ozone in those dark areas. In our paper we made the suggestion that, since these "holes" were found around the North and South poles, perhaps the appearance of blue/black in those cold locations was due to liquification or even crystallization of ozone, both of which lead to intense blue to black color to those areas. We also suggested that the "depletion" of ozone was perhaps because the existing methods of measuring ozone gas levels might not detect the physically altered ozone (liquid/solid). Then, during warmer months when more of the ozone returns to a gaseous form, the dark areas at the poles become smaller in size, and increased amounts of ozone are detected. We had also suggested that any reduction of ozone in the stratosphere due to degradation by CFCs, would be over the land masses of the industrialized countries, such as North America and Europe and not at the poles, where there are no human inhabitants. We maintain this explanation and offer the side-to-side comparison made by NASA (Fig. 3) of the appearance of the North pole during an exceptionally warm winter of 1984, with an extremely cold winter of 1997; this was interpreted by NASA as "abnormally warm, reducing ozone depletion, (in 1984) and the appearance in 1997 as "abnormally cold, resulting in increased seasonal depletion" (of ozone). This explanation is interesting in two respects. First, how does intense cold of any winter lead to depletion of ozone? Second, if depletion of ozone in an area leads to the appearance of deep blue-black color in that area, does NASA not imply that the usual blue color of earth from outer space is due to ozone? And, by extension, the color of sky as viewed from the surface of the earth is also due to the color of ozone? An interesting, related phenomenon is the occasional appearance of a bluish tinge on moon just before lunar eclipse, in addition to the normal reddish hue; this has been interpreted as being due to the color of ozone in the stratosphere.

Ozone is a pale blue gas on earth, but it becomes a deep blue liquid at around -112º C (-170º F) and a dark blue-black solid at an even colder temperature of -193º C (-315º F). The temperatures in that location does not descend to such levels, but the extremely rarefied air in that location (See Fig. 2) may impart unexpected effects on the process of condensation/crystallization. For example, when exposed to intense cold (as low as 2.7 Kelvin) and the extreme vacuum of deep space, water almost immediately takes on a globular shape, begins to boil first, before cooling and becoming ice, almost instantly after that. (30). This unusual effect on the behavior of water vapor in outer space is due to the combination of the ambient low temperature, as well as the markedly reduced air pressure prevailing there; this latter effect in turn is due to the markedly reduced gravitational pull from the earth. Whether this reduced gravity will have any other unknown effects on ozone is debatable. If in fact, the normal physical state of ozone in tropopause is as micro-droplets of liquid ozone all around the globe, rather than gaseous, our hypothesis becomes that much more likely. We can then state more confidently that around the North and South poles ozone in the tropopause becomes crystallized and then appears deep blue black in color.

CONCLUSION

We hope that we have made credible arguments in this paper why the blue color of daytime sky is due to the color of ozone in the tropopause and not due to scattering of short-wave blue photons by atmospheric air molecules. However, the sunsets and sunrises appear yellow-orange due to the sun's rays traversing the layers of dust close to the ground, and during that process the blue photons are lost, probably by absorption by the dust. Thus, this is closer to the Rayleigh scattering. Finally, only earth and Mars display blue skies, and these are the only planets that have defined layers of ozone, while all of the other planets also have varying amounts of gases and molecules in their atmospheres, and yet, they do not have blue skies. The true color of the sky is probably a deep blue, as seen in pristine locations and as the earth appears from the space, and the gradations of the color of the sky result from the dust in our atmosphere, especially in urban locations. Finally, we propose that ozone exists in the ozone layer of the tropopause in micro-droplets of a deep blue liquid state, but in extremely cold locations, it transforms to a darker, blue/black microcrystalline state; the arctic and the Antarctic, and around the highest peaks of the Himalayas are such locations, and the sky may actually appear blue/black in those areas.

ACKNOWLEDGEMENTS

I wish to acknowledge the excellent secretarial assistance of Ms. Rosie Gonzales and the technical assistance of Ms. Chantel Raghu. I am also indebted to Mr. Jeff Nichols for preparing the Figures 1a & 1b and Figure 2.

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