Ozone Layer Lab

Directions: Read this article (taken from excerpts found on [www.noaa.gov](http://www.noaa.gov)) about the ozone layer, underlining/highlighting important information as you go along. Then answer the questions that follow:

Ozone is created in the stratosphere when highly energetic solar radiation strikes molecules of oxygen (O2) and causes the two oxygen atoms to split apart. If a freed atom bumps into another )2, it joins up, forming zone (O3) This process is known as photolysis. Ozone is also naturally broken down in the stratosphere by sunlight and by a chemical reaction with various compounds containing nitrogen, hydrogen and chloring. These chemicals all occur naturally in the atmosphere in very small amounts.

In an unpolluted atmosphere there is a balance between the amount of ozone being produced and the amount of ozone being destroyed. As. Result, the total amount of ozone is in the stratosphere remains relatively constant. The mount of ozone within the stratosphere varies according to altitude. Ozone concentrations are heights between 19-23 km, but there are significant amounts up to 30 km. At these levels in the atmosphere however, the air is thin. If all the ozone in the stratosphere was compressed to ordinary atmosphere pressure at ground level, it would occupy a layer only 3 mm thick.

Ozone’s unique physical properties allow the ozone layer to act as our planets sunscreen, providing an invisible filter to help protect all life forms from the Sun’s damaging ultraviolet (UV) rays. Most incoming UF radiation is absorbed by ozone and prevented from reaching the Earth’s surface. Without the protective effect of ozone, life on Earth would not have evolved in the way it has

Stratospheric ozone is threatened by some of the human-made gases that have been released into the atmosphere, including those known as chlorofluorocarbons (CFCs). Once widely used as propellants in spray cans, refrigerants, electronic cleaning agents, and in foam and insulating products, the CFCs had been hailed as the “wonder chemical” But the very properties that make them useful chemical inertness non-toxicity, insolubility I water – also make them resistant to removal in the lower atmosphere

CFCs are mixed worldwide by the large-scale motions of the atmosphere and survive until, after 1-2 years, they reach the stratosphere and are broken down by ultraviolet radiation. The chlorine atoms within them are released and directly attach ozone. In the process of destroying ozone, the chlorine atoms are regenerated and getting to attach other ozone molecules. And so on, for thousands of cycles before the chloring atoms are removed from the stratosphere by other processes.

In response to the prospect of increasing ozone depletion, the governments of the world crafted the 1987 Montrell Protocol as a global means to address this global issue. As a result of the broad compliance with the Protocol and its Amendments and Adjustments and, of great significance, global accumulation of ozone-depleting gases has slowed and begun to decrease. This has reduced the risk of further ozone depletion. Now, with continued compliance, we expect recovery of the ozone later by the late 21st century. The International Day for the Preservation of the Ozone Layer, is 16 September, is now celebrated on the day the Montreal Protocol was agreed upon.

The table below shows the concentrations of ozone, in ozone units, in Earth’s atmosphere at different altitudes (One ozone unit is equal to 1012 molecules per cubic centimeter)

1. Construct a line graph of the ozone concentration in the atmosphere recorded at the time altitudes shown on the table above by plotting the data and connecting the points.



|  |  |
| --- | --- |
| Concentration of Ozone | |
| Altitude (km) | Ozone Units |
| 0 | 0.7 |
| 5 | 0.6 |
| 10 | 1.1 |
| 15 | 3.0 |
| 20 | 4.9 |
| 25 | 4.4 |
| 30 | 2.6 |
| 35 | 1.4 |
| 40 | 0.6 |
| 45 | 0.2 |
| 50 | 0.1 |
| 55 | 0.9 |

1. According to your graph, at which altitude is the concentration the greatest
2. In which layer of the atmosphere is the highest concentration of ozone found?
3. Why is the ozone layer important to life on Earth?
4. Describe how the ozone layer was put in danger
5. What was the human reaction to this problem?
6. Describe how the idea of dynamic equilibrium can be applied to the ozone layer

In the 1920’s, a team of researchers at General Motors Research Corporation lead by Thomas Midgley created the first chlorofluorocarbon (or CFC), which they called Freon. This team showed that the compound (made of carbon, hydrogen, chlorine, and fluorine) would be a safe alternative to the refrigerants available at the time. Later, other CFC’s were prepared, and the day found use in a wide variety of other places, including aerosol sprays, foams, and fire extinguishers. In the 1970’s, atmospheric chemists Mario Molina and Sherwood Rowland showed that reactions taking place when the normally stable CFC’s hit the lower temperatures and higher amounts of UV radiation in the stratosphere could break them down – and that once they were broken down, they could attack and destroy ozone molecules. An image from the first paper they published on this serious environmental issue appears below. The discovery that the CFC’s – even when present in extremely low concentrations in the stratosphere (as low as 1 in every 2,000 gas molecules) – could have this effect on the ozone layer was shocking to Sherwood and Rowland – and to the rest of the world as well.

There are three conditions that are needed for CFCs to be able to efficiently destroy ozone molecules and cause major decreases in ozone concentrations in the stratosphere: (1) solar radiation, (2) low temperatures, and (3) a surface on which the ozone-destruction process can occur. All three of those conditions are found in the stratosphere above the Antarctic during austral spring (i.e., September and October), and so the damage to the ozone layer there has been especially intense. In the spring in the Southern Hemisphere, the stratosphere above the Antarctic is especially ripe for this unfortunate bit of chemistry to happen, as the presence of Polar Stratospheric Clouds (PSCs; see picture of such clouds over Antarctica) and the increase in duration of sunlight, maximize the conditions needed for ozone-destroying reactions.

The video below shows how evidence for this thinning of the ozone layer – or ozone “hole” – was discovered in 1985 <https://youtu.be/lAjK_93NyV8>

1. What three conditions are needed for CFCs to cause a “hole” in the ozone layer over Antarctica?

When people hear the word oxygen, they think of the oxygen we breath that keeps us alive. That is one of two forms of oxygen: “regular” oxygen, which is made up of diatomic (two-atom) molecules (O2). There is a second form of oxygen: ozone, which is made up of triatomic (three-atom oxygen) molecules (O3). Ozone is produced in the stratosphere by ultraviolet (UV) radiation splitting a diatomic oxygen (O2) molecule in half. One of the oxygen atoms created by this splitting combines with another O2 molecule to form O3. The stratosphere has the highest concentration of ozone of any of the layers of atmosphere. The total amount of ozone that constitutes the atmosphere is measured in Dobson Units (DU), which is a value determine by measuring the concentration of ozone molecules in a column of air that extends from the Earth’s surface to the top of the atmosphere. Areas with values less than 220 Dobson Units are considered to have experienced severe ozone destruction. The image below presents a color-coded scale for Dobson Units that shows the 220-unit cut-off below which the concentration of ozone is recognized as being low enough that it poses a danger to human health. Please note which colors represent high ozone concentrations and which colors represent low ozone concentrations.



Below is an animation of ozone concentrations over Antarctica from 1979-2004.  The data were collected by instruments on NASA satellites. This animation shows total ozone in the Antarctic region along with the maximum ozone layer depth and size since the earliest measurements (from the Earth Probe instrument on the Total Ozone Mapping Spectrometer or TOMS satellite). This animation link below will represent concentration of ozone using the same color scheme as in the previous animation. Watch the entire animation (<https://www.youtube.com/watch?time_continue=1&v=QCOJvYfVXus&feature=emb_logo>) and keep note of changes in the sizes of the purple and blue areas and occurrences of red areas.

1. During what months of the year do the lowest ozone concentrations tend to occur? What season is this for Antarctica? Keep in mind that Antarctica is in the Southern Hemisphere.
2. Based on the three factors that you identified in Q7, Why do you think those months had the lowest ozone concentrations?

Moving about 12o in latitude north from the edge of Antarctica, one runs into Tierra del Fuego, an archipelago located off the tip of the South American mainland. One of the plants native to Tierra del Fuego is *Gunnera magellanica*, a creeping, flowering species that is fairly hardy. In 1997 a group of researchers lead by Rousseaux studied samples of this plant from across the archipelago to determine what effects on living organisms might have been caused by a migration of the ozone ‘hole’ (hereafter referred to as the severe destruction zone or SDZ) over that part of the Earth. This research particularly examined the damage to the DNA of *Gunnera magellanica* caused by the increase in UV radiation produced by the migration of the SDZ;

To consider for yourself the relationship between changes in the ozone concentration above Tierra del Fuego and the health of organisms living on it that Rousseaux and his colleagues were studying, first look at the animationbelow. It shows the changing ozone levels across the lower part of the southern hemisphere from 11 October 1997 to 16 October 1997, using data collected by instruments on NASA satellites. The ozone concentrations are represented using the same color scheme you have seen in the previous animations (the image below is available to remind you of that color scheme). As you look at the animation (<https://youtu.be/8iLPZcqsqew>) , try to note the precise timing when the levels of ozone over Tierra del Fuego were at their *lowest*.

Watch the animation again and notice how the ozone “hole” rotates clockwise. As shown in the image below, the stratospheric winds over the Antarctic Circle are the product of a pressure gradient from the lower latitudes to the South Pole and the rotating Earth causes the winds to the get deflected perpendicularly to the left; therefore, they are always blowing from west to east. The result is the Antarctic Vortex, and the ozone “hole” tends to be confined to the vortex.



Next, you will look at some of the data from the paper in which Rousseaux et al. discuss their findings. The figure below presents one section from that paper which contains, in order from top to bottom, images of the ozone concentration over Tierra del Fuego for October 14th and October 17th, 1997 (unfortunately, using a different color scheme than you seen in the previous animations); a graph showing the change in UV radiation reaching the surface of the Earth at Tierra del Fuego on those dates; and a graph on DNA damage measured in the *Gunnera magellanica* samples on those dates. Please answer the questions below the image concerning the relationships between these different things.



1. How did the change in ozone concentrations affect the amount of UV radiation reaching the Earth’s surface?
2. What affect did the change in UV radiation have on the vegetation?
3. Based on your answers to Q10 – Q11 and the data you examined, explain whether it would be reasonable for a scientist to state that, “Significant decreases in ozone concentration over a part of the Earth can cause serious damage to plant and animal DNA.”

Click [**Antarctica Ozone Data**](https://sites.gsu.edu/geog1112/files/2019/01/antarctica_ozone_data-2ifvbzj.xlsx) to open the file in Microsoft® Excel. This file contains yearly values for spring ozone concentration (in Dobson Units) over Antarctica and the size of the severe-destruction zones, which consists of values less than 220 Dobson Units, over Antarctica during spring. Its size is measured in millions of square kilometers. All data are derived from satellite measurements, and were obtained from [**NASA’s Ozone Hole Watch**](http://ozonewatch.gsfc.nasa.gov/).

You are going to convert that data into a graph within Excel using the following steps:

* Select cells in rows 1 through 41 of columns A, B, and C.
* Under the Insert tab, select Line
* Under the 2-D line options, click on first choice.
* The resulting graph shows yearly values of the minimum ozone concentration (upper in blue) and the area of the severe-destruction zone (or Hole Area, lower in red).

In order to better see the red line (Hole Area), right-click on that line, select Format Data Series, and then change the axis to the Secondary Axis.

The graph will now have the units for Ozone Concentration on the left vertical axis and will have the unit for Hole Area on the right vertical axis. Reformatting the graph as you just did should allow you to better see the relationship between the two. Feel free to play around with the graph to make it larger, wider, etc.

1. How would you describe the trends in the data over time for the spring ozone concentration over Antarctica from 1979 to 1989? i.e. What do you see happening to the ozone concentration over Antarctica in the time since the Montreal Protocol went into force?
2. How would you describe the trends in the data over time for the Hole Area over Antarctica from 1979 to 1989? i.e. What do you see happening to the Hole Area over Antarctica in the time since the Montreal Protocol went into force?
3. Based on your answers to Q13 and Q14, what is the relationship between ozone concentration and Hole Area?
4. You should notice in the graph that between 1987 and 1988 and then again between 2001 and 2002, there were very dramatic decreases in the Hole Area (or severe destruction zone). If the amount of UV radiation and the amount of ozone–destroying chemicals did not change significantly over those two periods, why did the Hole Area change so dramatically?
5. Based on your analysis of the graph, what effect has the Montreal Protocol had on the stratospheric ozone layer?
6. You should have noticed that the Hole Area leveled off but did not decrease significantly since the Montreal Protocol was put in place; why has it not decreased significantly yet?

Below is a NASA animation which shows the ozone concentrations over the western hemisphere from 1979 to 2065. The concentration of ozone will be represented using the same Dobson Unit scale that you have seen before. (Just in case you have forgotten the scale is shown below.) The visualizations present two scenarios: (1) “Projected,” which assumes the current rate of CFC emissions in the atmosphere; and (2) “World Avoided,” where the rate of CFC emissions is assumed to be that of the period before regulation. Therefore, “World Avoided” has much higher rates of CFC emissions than does “Projected” from 1989 to 2065. Watch the entire animation (<https://youtu.be/5MeKqJrMrQI>) and pay particular attention to areas of low ozone concentration just to the east of the southeastern United States (i.e. over the far western North Atlantic Ocean).

1. What effect should the Montreal Protocol have on the stratospheric ozone layer in future decades?

1. If the phasing out and elimination of ozone-destroying chemicals had not occurred, then what do you expect would happen to the rate of UV-caused health problems among people between now and 2060?