AP® ENVIRONMENTAL SCIENCE
2013 SCORING GUIDELINES

Question 3

(a) Identify the type of solar radiation that is absorbed by stratospheric ozone and describe one human health benefit that results from the absorption of this solar energy.
(2 points: 1 point for identifying ultraviolet (UV, UV-B, or UV-C) radiation as the type absorbed by stratospheric ozone and 1 point for a correct description of a health benefit resulting from the absorption of UV radiation in the stratosphere; only the first type of solar radiation and health effect can earn points)

The following are acceptable human health benefits resulting from the absorption of UV radiation in the stratosphere:

- Low rates of skin cancer (e.g., basal cell carcinoma, squamous cell carcinoma, melanoma)
- Low rates of sunburns
- Low rates of eye damage (e.g., cataracts)

(b) The absorption of solar energy by stratospheric ozone causes ozone molecules to undergo chemical decomposition and formation. Describe the chemical processes that lead to this natural balance between decomposition and formation of stratospheric ozone (you may use chemical equations in your answer).
(2 points: 1 point for a correct description of the chemical decomposition of stratospheric ozone and 1 point for a correct description of the formation of stratospheric ozone)

Correct descriptions of the chemical decomposition of stratospheric ozone include one of the following:

- Ozone absorbs UV radiation, producing an oxygen molecule and an oxygen atom
- Ozone molecules absorb UV radiation, producing oxygen molecules
- $O_3 + UV \rightarrow O_2 + O$
- $2O_3 + UV \rightarrow 3O_2$

Correct descriptions of the chemical formation of stratospheric ozone include one of the following:

- An oxygen molecule reacts with an oxygen atom to form ozone
- Oxygen molecules absorb UV radiation, forming ozone molecules
- $O_2 + O \rightarrow O_3$
- $3O_2 + UV \rightarrow 2O_3$

OR:

The chemical decomposition and formation of stratospheric ozone may be described together:

- Ozone absorbs UV radiation producing an oxygen molecule and an oxygen atom, which then react to form ozone
- $O_3 + UV \rightarrow O_2 + O \rightarrow O_3$

(Note: This combined explanation earns both points.)

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Question 3 (continued)

(c) The Montreal Protocol of 1987 provided a global framework to phase out chlorofluorocarbon (CFC) production and use. Although the Montreal Protocol has led to a dramatic decrease in CFCs released into the atmosphere, stratospheric ozone destruction has decreased only slightly.

(i) Explain the process by which CFCs lead to the destruction of stratospheric ozone. (You may use chemical equations in your answer.)
(2 points: 1 point for a correct description of the decomposition of CFCs and 1 point for a correct description of the reaction of ozone with chlorine)

Correct descriptions of the decomposition of CFCs include one of the following:

- Absorption of UV radiation by CFC molecules releases chlorine atoms
- $CCl_3F + UV \rightarrow CCl_2F + Cl$

Correct descriptions of the destruction of stratospheric ozone include one of the following:

- Chlorine atoms break down ozone molecules
- $Cl + O_3 \rightarrow ClO + O_2$

(ii) Explain why the rapid decrease in CFC emissions has not led to a similarly rapid decrease in the destruction of stratospheric ozone.
(1 point can be earned for a correct explanation linking the absence of a rapid decrease in the destruction of stratospheric ozone with one of the following):

- The slow migration of CFCs into the stratosphere.
- The long lifetime of CFCs and/or chlorine in the stratosphere.
- The continued release of other ozone-depleting substances.

(d) Identify a human activity that leads to the formation of tropospheric ozone as a secondary pollutant and explain why tropospheric ozone levels peak in the daytime.
(2 points: 1 point for a correct human activity and 1 point for correctly explaining that sunlight is required to form tropospheric ozone; only the first human activity can earn points)

The following are acceptable human activities:

- Burning fossil fuels (e.g., operating motor vehicles, using landscaping equipment, electric power generation, industrial production)
- Releasing VOCs (e.g., pumping gas, using solvent-based paints)

The following are acceptable explanations for why tropospheric ozone levels peak in the daytime:

- Sunlight is required to form tropospheric ozone
- Tropospheric ozone is created by photochemical reactions

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(e) Identify one negative ecological impact and one negative human health impact that result from the formation of tropospheric ozone.
(2 points: 1 point for a correct negative ecological impact and 1 point for a correct negative human health impact; only the first impact in each category can earn points)

The following are acceptable negative ecological impacts:

- Damages plant tissue
- Reduces primary productivity/inhibits photosynthesis
- Stresses plants, making them more vulnerable to disease and pests
- Irritates the respiratory system of animals
- The statement that ozone is a greenhouse gas or contributor to climate change/global warming, along with an associated negative ecological impact (e.g., habitat loss, loss of biodiversity, shifting biomes)

The following are acceptable negative human health impacts:

- Irritates the respiratory system (e.g., throat irritation, coughing, decreased lung function)
- Associated with diseases of the respiratory system (e.g., asthma, bronchitis, etc.)
- Irritates eyes
- The statement that ozone is a greenhouse gas, or contributor to climate change/global warming, along with an associated negative human health impact (e.g., increased range of disease vectors resulting in increased mortality, increased risk of harm from severe weather events, increased hunger resulting from decreased crop yields)

3. Ozone (O_3) is an atmospheric trace gas that occurs naturally in the stratosphere. It is also formed as a consequence of human activity in the troposphere, immediately above Earth's surface. The location of ozone in the atmosphere determines whether the gas protects or damages the environment.

   (a) **Identify** the type of solar radiation that is absorbed by stratospheric ozone, and **describe** one human health benefit that results from the absorption of this solar energy.

   (b) The absorption of solar energy by stratospheric ozone causes ozone molecules to undergo chemical decomposition and formation. **Describe** the chemical processes that lead to this natural balance between decomposition and formation of stratospheric ozone (you may use chemical equations in your answer).

   (c) The Montreal Protocol of 1987 provided a global framework to phase out chlorofluorocarbon (CFC) production and use. Although the Montreal Protocol has led to a dramatic decrease in CFCs released into the atmosphere, stratospheric ozone destruction has decreased only slightly.

      i. **Explain** the process by which CFCs lead to the destruction of stratospheric ozone. (You may use chemical equations in your answer.)

      ii. **Explain** why the rapid decrease in CFC emissions has not led to a similarly rapid decrease in the destruction of stratospheric ozone.

   (d) **Identify** a human activity that leads to the formation of tropospheric ozone as a secondary pollutant and explain why tropospheric ozone levels peak in the daytime.

   (e) **Identify** one negative ecological impact and one negative human health impact that result from the formation of tropospheric ozone.

(a) Stratospheric ozone absorbs ultraviolet radiation. Without ozone absorbing ~~stratospheric ozone~~ ultraviolet, there would be an increase in the amount of skin cancer that occurs.

(b)
- When O_3 is struck by ultra violet light the ozone breaks into ~~an~~ a single oxygen atom and an oxygen molecule

  $O_3 + UVC \longrightarrow O + O_2$

- When UV light reacts with molecular oxygen the oxygen ~~molecule~~ atom splits into two oxygen atoms.

  $O_2 + UV \longrightarrow O + O$

- The molecular oxygen from the first reaction binds with one of the free oxygen atoms and forms ozone.

  $O_2 + O \longrightarrow O_3$

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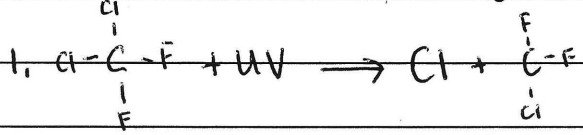
· This process occurs continually in the stratosphere, which leads to the natural balance between the decompesition and formation of ozone.

(c) (i) CFC's make their way to the poles of earth and enter the stratosphere. Here UV light reacts with the CFC molecule and ~~breaks~~ causes a chlorine atom to be lost from the molecule. This chlorine atom reacts with ozone to form chlorine monoxide (ClO), and leaving an oxygen molecule (O_2). The ClO reacts with another ozone molecule to release the chlorine atom and produce two oxygen molecules. This process repeats over and over. One chlorine atom can destroy over 100,000 ozone molecules.

Chemical Formulas:

↳ 1. 

2. The chlorine atom binds with ozone to form ClO and O_2

$$Cl + O_3 \rightarrow ClO + O_2$$

3. This chlorine monoxide reacts with another ozone molecule, freeing the chlorine atom to react with other ozone molecules

$$ClO + O_3 \rightarrow Cl + 2O_2$$

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(c) (ii) The rapid decrease in CFC emissions has not led to a similarly rapid decrease in destruction of stratosphere ozone because CFC's take a long time to travel to the poles and affect the ozone in the stratosphere. It takes many years for the CFC to reach to stratosphere and break apart ozone molecules, therefore we will see a very large depletion in the ozone in upcoming years because those CFC's released finally reached the stratosphere.

(d) A human activity that leads to the formation of troposphere ozone is the use of a car (car exhaust). Because cars create NO_x and ozone forms when uv light breaks apart NO_2 into O and NO, this ultimately creates ozone.

$$NO_2 + UV \rightarrow NO + O$$

$$O + O_2 \rightarrow O_3$$

Troposphere ozone levels peak at daytime because there are the greatest amounts of cars on the road at this time (rush hour traffic).

(e) Ozone, in the troposphere, is harmful to plants ~~tissues~~ because it destroys plant tissues. For humans, troposphere ozone is a respiratory irritant and can result in eye irritation and inflamation of the lungs.

3. Ozone (O_3) is an atmospheric trace gas that occurs naturally in the stratosphere. It is also formed as a consequence of human activity in the troposphere, immediately above Earth's surface. The location of ozone in the atmosphere determines whether the gas protects or damages the environment.

   (a) **Identify** the type of solar radiation that is absorbed by stratospheric ozone, and **describe** one human health benefit that results from the absorption of this solar energy.

   (b) The absorption of solar energy by stratospheric ozone causes ozone molecules to undergo chemical decomposition and formation. **Describe** the chemical processes that lead to this natural balance between decomposition and formation of stratospheric ozone (you may use chemical equations in your answer).

   (c) The Montreal Protocol of 1987 provided a global framework to phase out chlorofluorocarbon (CFC) production and use. Although the Montreal Protocol has led to a dramatic decrease in CFCs released into the atmosphere, stratospheric ozone destruction has decreased only slightly.

      i. **Explain** the process by which CFCs lead to the destruction of stratospheric ozone. (You may use chemical equations in your answer.)

      ii. **Explain** why the rapid decrease in CFC emissions has not led to a similarly rapid decrease in the destruction of stratospheric ozone.

   (d) **Identify** a human activity that leads to the formation of tropospheric ozone as a secondary pollutant and explain why tropospheric ozone levels peak in the daytime.

   (e) **Identify** one negative ecological impact and one negative human health impact that result from the formation of tropospheric ozone.

3. a) Ozone in the stratosphere absorbs ultraviolet radiation from the sun. This means that humans are not exposed to as much ultraviolet radiation, and as a result, have lower rates of skin cancer than they would if the ozone was not in the stratosphere.

b) Ozone breaks down into oxygen when its molecules are split by solar energy, following the chemical formula:

$$2O_3 \longrightarrow 3O_2$$

As seen in the equation, this results in the formation of molecular oxygen molecules.

Like wise, Ozone is formed in the stratosphere by solar energy, following the chemical equations:

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$O_2 \rightarrow O + O$

$O + O_2 \rightarrow O_3$

where single atoms of oxygen act as an intermediate.

c) i. The chlorine atoms in CFCs are responsible for the breakdown of ozone, acting as a catalyst in the equations

$Cl + O_3 \rightarrow ClO + O_2$

$ClO + O_3 \rightarrow Cl + 2O_2$

These reactions happen because ~~chlorine~~ oxygen has a higher affinity for chlorine than it does itself.

ii. Chlorine from CFCs remains in the stratosphere because it only acts as a catalyst in the breakdown of oxygen (chlorine ions are both products and reactants). Therefore, it continues to breakdown ozone in the stratosphere, despite the fact that CFC emissions have greatly decreased.

d) Tropospheric ozone is formed as a secondary pollutant by chemicals that are produced through automobile exhaust. Ozone is produced by a reaction that requires sunlight, and thus is present at highest levels in the daytime.

e) Troposphere is a component of photochemical smog and causes eye irritation and respiratory illness in humans. It is also harmful to ecosystems, as it can cause thermal pollution, ~~[illegible]~~ making

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Species live in unbearable temperatures.

3<1

3. Ozone (O_3) is an atmospheric trace gas that occurs naturally in the stratosphere. It is also formed as a consequence of human activity in the troposphere, immediately above Earth's surface. The location of ozone in the atmosphere determines whether the gas protects or damages the environment.

   (a) **Identify** the type of solar radiation that is absorbed by stratospheric ozone, and **describe** one human health benefit that results from the absorption of this solar energy.

   (b) The absorption of solar energy by stratospheric ozone causes ozone molecules to undergo chemical decomposition and formation. **Describe** the chemical processes that lead to this natural balance between decomposition and formation of stratospheric ozone (you may use chemical equations in your answer).

   (c) The Montreal Protocol of 1987 provided a global framework to phase out chlorofluorocarbon (CFC) production and use. Although the Montreal Protocol has led to a dramatic decrease in CFCs released into the atmosphere, stratospheric ozone destruction has decreased only slightly.

      i. **Explain** the process by which CFCs lead to the destruction of stratospheric ozone. (You may use chemical equations in your answer.)

      ii. **Explain** why the rapid decrease in CFC emissions has not led to a similarly rapid decrease in the destruction of stratospheric ozone.

   (d) **Identify** a human activity that leads to the formation of tropospheric ozone as a secondary pollutant and explain why tropospheric ozone levels peak in the daytime.

   (e) **Identify** one negative ecological impact and one negative human health impact that result from the formation of tropospheric ozone.

3. a) Ultra-violet radiation is absorbed by stratospheric ozone. This decreases the rate of skin cancer among human beings.

b) The natural oxygen (O_2) in the atmosphere combines with the oxygen atoms from other compounds in the air, forming O_3. However, other elements in those compounds, such as carbon and sulfur, are highly reactive and bond themselves with the third oxygen atom in the ozone molecule, creating a constant decomposition and formation of ozone in the stratasphere.

3C2

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c) i. CFCs destroy stratospheric ozone because they are made of highly reactive atoms like sulfur and nitrogen. The sulfur and nitrogen atoms bond with oxygen atoms in O_3, rendering it O_2. When sulfurous oxides and nitrous oxides form, they create a positive feedback cycle of CFCs breaking down ozone and multiplying in number in the stratosphere.

ii. Although CFC emissions have decreased exponentially, the CFCs that were initially in the atmosphere remain there, still multiplying and breaking down ozone. Therefore, it will take many years for stratospheric CFC levels to decrease at the rate that CFC emissions have.

d) Emissions from coal-burning power plants form tropospheric ozone. Ozone levels peak in the daytime because the NO_x and SO_x emissions form in sunlight.

e) Ecologically, tropospheric ozone decreases agriculture because crops die from the toxins in the air. Tropospheric ozone affects humans by increasing the frequency of asthma and bronchitis.

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2013 SCORING COMMENTARY

Question 3

Overview

The intent of this question was to have students demonstrate their understanding of the different roles ozone plays in the Earth's atmosphere. Students were asked about the formation of both stratospheric and tropospheric ozone, the natural and anthropogenic destruction of stratospheric ozone, and the impacts that the ozone in both layers of the atmosphere has on life on Earth.

Sample: 3A
Score: 10

Two points were earned in part (a): 1 point was earned for identifying the type of radiation absorbed by stratospheric ozone as ultraviolet radiation and 1 point was earned for identifying an increase in the amount of skin cancer in the absence of ozone as a human health benefit that results from the absorption of UV radiation in the stratosphere. Two points were earned in part (b): 1 point was earned for the correct description that "when O_3 is struck by ultraviolet light the ozone breaks into a single oxygen atom and an oxygen molecule" and 1 point was earned for explaining that "the molecular oxygen from the first reaction binds with one of the free oxygen atoms and forms ozone." Three points were earned in part (c). Two points were earned in part (i): 1 point was earned for explaining that UV light causes a chlorine atom to be lost from a CFC molecule and 1 point was earned for explaining that ozone reacts with chlorine to form chlorine monoxide and oxygen. One point was earned in part (ii) for explaining that CFCs take a long time to travel to the stratosphere. One point was earned in part (d) for identifying "use of a car" as a human activity that leads to the formation of tropospheric ozone. Two points were earned in part (e): 1 point was earned for identifying "destroys plant tissues" as a negative ecological impact and 1 point was earned for identifying tropospheric ozone as a respiratory irritant to humans.

Sample: 3B
Score: 8

Two points were earned in part (a): 1 point was earned for identifying the type of radiation absorbed by stratospheric ozone as ultraviolet radiation and 1 point was earned for identifying "lower rates of skin cancer" as a human health benefit that results from the absorption of UV radiation in the stratosphere. One point was earned in part (b) for the correct chemical equation for ozone formation, "$O + O_2 \rightarrow O_3$." No point was earned for the decomposition equation since it did not include UV radiation. Two points were earned in part (c): 1 point was earned in part (i) for the correct chemical equation for ozone destruction, "$Cl + O_3 \rightarrow ClO + O_2$," and 1 point was earned in part (ii) for explaining that chlorine remains in the stratosphere. Two points were earned in part (d): 1 point was earned for identifying "automobile exhaust" as a human activity that leads to the formation of tropospheric ozone and 1 point was earned for stating that "ozone is produced by a reaction that requires sunlight." One point was earned in part (e) for identifying eye irritation as a negative human health impact.

Sample: 3C
Score: 6

Two points were earned in part (a): 1 point was earned for identifying the type of radiation absorbed by stratospheric ozone as ultraviolet radiation and 1 point was earned for identifying "decreases the rate of skin cancer" as a human health benefit that results from the absorption of UV radiation in the stratosphere. One point was earned in part (b) for a correct description of the formation of stratospheric ozone from O_2 and oxygen atoms. One point was earned in part (c)(ii) for explaining that CFCs remain in

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the atmosphere for many years. One point was earned in part (d) for identifying "emissions from coal-burning power plants" as a human activity that leads to the formation of tropospheric ozone. One point was earned in part (e) for identifying "increasing the frequency of asthma" as a negative human health impact. The reference to "crops die from the toxins in the air" did not earn a point for describing an ecological impact.