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.

GO ON TO THE NEXT PAGE.

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.)

AP® ENVIRONMENTAL SCIENCE
2013 SCORING GUIDELINES

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

Question 3 (continued)

(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)