CHAPTER 21

CLIMATE CHANGE AND OZONE LOSS

Summary

1. The Earth has undergone prolonged periods if global warming and global cooling in the past. This is supported by sediment and ice core samples. For the last 12 000 years, we have been in an interglacial period.

2. Clouds, water vapour, and other gases—collectively known as greenhouse gases (GHGs)—trap infrared energy radiated from the Earth's surface. In turn, this trapped heat is radiated; some is radiated into space, and the rest warms the troposphere and the Earth's surface. The GHGs in the greatest concentrations are water vapour and carbon dioxide. In the last few decades, concentrations of the GHGs, CO_2, CH_4, and N_2O have increased dramatically. An increased use of fossil fuels, deforestation and clearing of grasslands, livestock production, the use of inorganic fertilizers, and rice cultivation have all contributed large amounts of GHGs to the atmosphere.

3. Mean global temperatures have risen by 0.7°C since 1861. Factors that influence changes in the Earth's average surface temperature include changes in the solar output, the Earth's reflectivity, the ability of oceans to store carbon dioxide, the ocean currents, the average sea level, cloud cover, and air pollution. The scientific consensus is that the troposphere is warming.

4. The Earth's temperature is affected by the amount of CO_2 stored in the oceans, the surface and deep movements of ocean currents, the amount of cloud cover, air pollutants, photosynthetic rates, and methane emissions. The Earth's mean temperature is predicted to rise from 1.4 to 5.8°C between 2000 and 2100. A 3°C increase in temperature could cause sea levels to rise by 7 metres. A warmer Earth could disrupt and destroy ecosystems, affect agriculture and, increase flooding. Canada would experience longer growing seasons; higher summer and winter temperatures; changes in precipitation, forest distribution, and ice cover; more fires, insect damage; and increased flooding.

5. To deal with the projected global warming, we could do more research before acting (wait and see), act now to reduce the risks from climate change brought about by global warming, and act now as part of a no-regrets policy. To prevent global warming, we should limit fossil fuel use, shift from coal to natural gas use, promote energy-efficient technologies in developing countries, improve energy efficiency, shift to renewable resources, reduce deforestation, use sustainable agriculture, limit urban sprawl, reduce poverty, and slow population growth.

6. Stratospheric ozone keeps about 95% of the sun's harmful UV rays from reaching Earth. As a result of human activities, ozone concentrations are greatly reduced, especially each spring in Antarctica. Human activities that cause ozone depletion include emissions of chlorofluorocarbons, methyl bromide, hydrogen chloride, carbon tetrachloride, methyl chloroform, and others. We need to prevent ozone depletion to avoid sunburns, cataracts, skin cancers, immune suppression, reduced crop yields, reduced seafood supplies, decreased

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forest productivity, increased acid deposition, increased photochemical smog, and global warming.

7. To phase out ozone-depleting chemicals many nations signed the Montreal Protocol (1987) and the Copenhagen Protocol (1992). It is predicted that ozone concentrations should return to 1980 levels by 2050. Evidence shows that ozone depletion has helped cool the troposphere, offsetting global warming from GHG emissions.

Key Concepts and Learning Outcomes

After completing this chapter, students should be able to answer the following key questions.

21-1 How Have the Earth's Temperature and Climate Changed in the Past? Climate Change Is Not New

A. Temperature and climate have been changing throughout Earth's history.
   1. Climate shifts have occurred due to volcanic emissions, changes in solar input, continents moving on shifting plates, meteor strikes, and other factors.
   2. Alternating cycles of freezing and thawing are known as glacial and interglacial periods.

21-2 How Do Scientists Study Climate Change? Drill Holes and Make Measurements

A. Geologic records and atmospheric measurements provide a wealth of information about past atmospheric temperatures and climate.
   1. Antarctic ice cores indicate that the current interglacial period could last another 15 000 years.
   2. Sediment cores can also be analyzed for pollen, fossils, and other clues about the types of plants that lived in the past.
   3. Direct temperature records go back to 1861.
   4. Air samples are collected at different locations and analyzed for changes in chemical composition in the troposphere.
   5. The Intergovernmental Panel on Climate Change (IPCC) was formed to evaluate possible future climate changes. Conclusions and projections use several levels of certainty: virtually certain (more than 99% probability), very likely (90–99% probability), and likely (66–90% probability).

21-3 What Role Does the Natural Greenhouse Effect Play in the Earth's Temperature and Climate? A Giver of Life

A. Certain gases in the atmosphere absorb heat and warm the lower atmosphere.
   1. A natural process called the greenhouse effect warms the lower troposphere and surface.
   2. Heat is absorbed when liquid surface water evaporates. The water vapour rises, condenses to form droplets, and releases its heat in the troposphere.
   3. The Earth's average surface temperature is about 15 ^{o}C because of the greenhouse effect.

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21-4 What Are the Major Greenhouse Gases? Two Important Molecules

A. The two major greenhouse gases (GHGs) are water vapour and carbon dioxide.
   1. Measurements of CO_2 in glacial ice correlate fairly closely with estimated variations in the average global surface temperature during the past 400 000 years.

21-5 How Have Human Activities Affected Tropospheric Concentrations of Greenhouse Gases? Messing with the Carbon Cycle

A. GHGs are at higher levels than they have been for 400 000 years. Humans have increased levels of greenhouse gases (GHGs) in the troposphere by burning fossil fuels, farming (especially rice agriculture and livestock), using inorganic fertilizers, deforestation, burning forests, etc.

21-6 Which Country Is the Largest Greenhouse Gas Emitter? No Longer the United States

A. Until 2006, the United States released more GHGs per person than any other country.
   1. Because of coal-intensive economy, China now produces more CO_2 than the United States.
   2. However, the per capita production of CO_2 of the United States is four times that of China.
   3. The United States also emits large quantities of CH_4, most of which comes from landfills, domestic livestock, natural gas, oil, and coal mining.
   4. Canada has 0.5% of the world population, but produces less than 2% of global emissions.

21-7 Is the Troposphere Warming? Very Likely

A. There is evidence that the Earth's troposphere is warming.
   1. Five findings of the IPCC that support the scientific consensus that the troposphere is very likely getting warmer are as follows:
      a. The past three decades were each warmer than the previous one, and the 30 years from 1983 to 2012 were very likely the warmest 30-year period of the past 800 years.
      b. Since 1868, the average global temperature has risen 0.85°C, with the greatest increases occurring since 1980.
      c. It is virtually certain that the upper 700 metres of the oceans became warmer globally between 1971 and 2010, with the top 75 metres experiencing the greatest rate of warming.
      d. Glaciers and floating sea ice in some parts of the world are melting and shrinking.
      e. The world's average sea level rose by 0.19 metres during the past century.
   2. Global warming refers to temperature increases in the troposphere, which can cause climate change.
   3. Global climate change is a broader term that refers to changes in any aspects of the Earth's climate.

21-8 How Do Scientists Model Changes in the Earth's Temperature and Climate? Computer Models as Crystal Balls

A. Scientists use complex mathematical models to predict future changes in the Earth's average temperature.
   1. Scientists have developed global climate models (coupled global circulation models).

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2. Modellers develop a three-dimensional representation of how energy, air masses, and moisture flow through the atmosphere.
3. These models provide scenarios of what is likely to happen based on various assumptions and data fed into the model.

21-9 What Is the Scientific Consensus about Future Changes in the Earth's Temperature? Hotter Times Ahead

A. Climate scientists agree that human activities have influenced recent temperature increases and will lead to more significant temperature increases during this century.
   1. Three major findings of the IPCC 2013 report are as follows:
      a. Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. By 2081–2100, the temperature increase is likely to be between 0.3°C and 1.7°C under the most optimistic scenario (which assumes lower greenhouse gas emissions).
      b. The level of surface warming by the late 21st century will be determined mainly by the cumulative emissions of CO_2, past and future, and by natural climate variability.
      c. The report indicates that "Many aspects of climate change and associated impacts will continue for centuries, even if anthropogenic emissions of greenhouse gases are stopped. The risks of abrupt or irreversible changes increase as the magnitude of the warming increases."
   2. A few scientists disagree with the consensus about future temperature changes. They claim that too little is known about how the Earth's climate works.

21-10 Why Should We Be Concerned About a Warmer Earth? The Speed of Change Is What Counts

A. A rapid increase in the temperature of the troposphere would give living organisms little time to deal with the effects.
   1. The projected increase will be the most rapid temperature change in the past 1000 years.
   2. Rapid temperature changes can affect the availability of water resources by altering evaporation and precipitation rates. Ocean currents could shift and sea levels could rise and flood coastal wetlands, cities, and low-lying islands.

21-11 Can the Oceans Store More CO_2 and Heat? We Do Not Know

A. There is uncertainty about how much CO_2 and heat the oceans can remove from the troposphere and how long they might remain in the oceans.
   1. Oceans help moderate the Earth's average surface temperature by absorbing both CO_2 and heat from the atmosphere.
   2. Ocean currents are also important for the transfer of heat.
   3. The movement and speed of the ocean currents may contribute to significant alterations in temperature patterns in the northern hemisphere.
   4. Physical oceanographers have found that the tropical oceans are saltier, and the polar oceans are less salty, than they were 40 years ago. This suggests that global warming may be accelerating the global water cycle.
   5. Changes in the hydrologic cycle may affect global precipitation patterns. It may result in regional cooling because of changes in the distribution of water vapour and movement of ocean currents.

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21-12 How Might Stored CO_2 Affect Water Chemistry? Ocean Acidification

A. Studies have shown that the ocean has become more acidic by 0.1 pH units since the industrial revolution.
   1. pH levels could drop by 0.3 pH units before the end of this century.
   2. Calcium carbonate would be less available to be precipitated into the shells and skeletons of marine organisms.
   3. Corals would be negatively impacted since they have large requirements for calcium carbonate to build their exoskeletons, and since they are already stressed by warming seas.
   4. Schemes that involve disposal of CO_2 into the ocean now seem inadvisable.

21-13 How Might Changes in Cloud Cover Affect the Troposphere's Temperature? Another Uncertainty

A. One of the largest unknowns in global warming is the change in the distribution of clouds.
   1. Additional clouds may have a warming effect by absorbing and releasing more heat into the troposphere, or a cooling effect by reflecting more sunlight back into space.
   2. Several factors will affect the net impact of more cloud cover, such as the amount of water vapour in the troposphere, whether clouds are thin or thick, cloud coverage and altitude, and the size and number of water droplets or ice crystals formed in clouds.

21-14 How Might Outdoor Air Pollution Affect the Troposphere's Temperature? A Temporary Effect

A. Aerosol pollutants and soot can warm or cool the troposphere, but these effects will decline with a reduction in outdoor air pollution.
   1. Some aerosols, such as sulphate particles, tend to cool the air.
      a. Sulphate particles also cool the lower atmosphere by serving as condensation nuclei that form clouds.
   2. Soot—the black carbon particulate matter produced by coal burning, cooking fires, forest fires, and diesel exhaust—is a factor that warms the atmosphere.
   3. Scientists don't expect aerosol pollutants to have a major effect on global warming.
      a. They are only in the atmosphere for a short time.
      b. They are also being reduced, especially in developed countries.

21-15 Can Increased CO_2 Levels Stimulate Photosynthesis and Remove More CO_2 from the Air? A Temporary and Limited Effect

A. Increased CO_2 in the troposphere could increase photosynthesis and remove more CO_2, but several factors can limit or offset this effect.
   1. Old-growth Amazon rain forests are experiencing rapid changes in species composition.
   2. After large trees reach maturity and die out, less CO_2 is absorbed by the young trees.

21-16 How Might a Warmer Troposphere Affect Methane Emissions? Accelerated Warming

A. Acceleration of global warming may occur because of methane gas released from two major sources:
   1. bogs, and wetlands, and

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2. methane hydrates trapped under Arctic permafrost.

21-17 What Are Some Possible Effects of a Warmer Troposphere? Winners and Losers

A. A warmer troposphere could have both beneficial and harmful effects. These are listed in Figure 21-16.
   1. People in the poorer tropical and subtropical countries will feel the harmful effects of moderate global warming the most.
   2. Premature deaths from the side effects of global warming and increased incidences of disease are estimated to double the death toll by 2020.
   3. The IPCC predicts many other effects due to tropospheric warming.
      a. Many ecosystems (coral reefs, polar seas, coastal wetlands, Arctic and alpine tundra, and high-elevation ecosystems) will be greatly disrupted.
      b. Fragmented habitats may affect the ability of organisms to adjust their ranges.
      c. A decrease in snow pack will affect the amount of water available for agriculture.
      d. The sea level could rise by 7 metres if most of the ice in Greenland and the Canadian Arctic melts.
         1) Coastal cities would flood.
         2) Low-lying land would be lost.
         3) Productive coastal estuaries and wetlands would be disrupted, affecting fisheries.
         4) Freshwater coastal aquifers would become contaminated with salt water.

21-18 How Might a Warmer Troposphere Affect Canada? Mostly Bad News

A. In Canada, a warmer troposphere could extend the growing season.
   1. Summers and winters would be warmer.
   2. British Columbia's coasts would flood and erode as sea levels rise.
      a. Expensive structures would have to be built to control floods.
      b. After the glaciers melted, stream flow would be lower, affecting fisheries and hydro production.
   3. The Prairies would have a longer growing season, but more droughts.
      a. More irrigation would be necessary.
      b. Lakes and wetlands would disappear, affecting nesting waterfowl.
   4. The Arctic ice and permafrost would be affected, disrupting people and wildlife.
   5. The boreal forest would need to shift northward over time. There would be
      a. more fires,
      b. more insect damage, and
      c. more threats to wildlife.
   6. The Great Lakes area would have more heat waves, resulting in the following:
      a. more serious air pollution and health problems
      b. lower lake levels, affecting hydro and shipping
      c. more severe weather events
      d. a greater need to irrigate in summer
   7. In Eastern Canada, higher sea levels would lead to flooding of coastal cities, erosion of beaches and coastlines, a loss of wetlands, increased damage to forests from insect pests, and regional fisheries under threat due to changes in fish migrations.

21-19 What Are Our Options? The Great Climate Debate

A. There is disagreement over what we should do about the threat of global warming.

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1. Scientists debate the causes, how rapidly the changes might occur, the effects on humans and ecosystems, and the responses that should be taken.
2. Economists and policymakers disagree on whether
   a. economic costs of reducing greenhouse gas emissions are higher than the economic benefits;
   b. developed countries, developing countries, or both should take responsibility for reducing greenhouse gases; and
   c. actions to reduce greenhouse gas emissions should be taken on a voluntary or mandated basis.
3. Three schools of thought have emerged from this controversy.
   a. Do more research before acting.
   b. Act now to reduce the risks from climate change brought about by global warming. (Apply the precautionary principle).
   c. Act now as part of a no-regrets strategy.

21-20 What Can We Do to Reduce the Threat? Conserve Energy, Use Renewable Energy, and Intercept Greenhouse Gas Emissions

A. The solutions offered for slowing the rate and degree of global warming come down to the following three major strategies:
   1. Improve energy efficiency to reduce fossil fuel use
   2. Shift from carbon-based fossil fuels to a mix of carbon-free renewable energy resources
   3. Sequester or store as much CO_2 as possible in soil, in vegetation, underground, and in the deep ocean

21-21 Can We Remove and Store (Sequester) Enough CO_2 to Slow Global Warming? Are Output Approaches the Answer

A. We can remove and store CO_2 by the following measures (Figure 21-20).
   1. Plant trees that will store CO_2 in biomass.
   2. Soil sequestration is a possibility, but warmer temperatures can increase organic matter decomposition in soil, with CO_2 then being returned to the troposphere.
   3. Reduce soil CO_2 and N_2O release by altering agricultural practices to include no-till cultivation and letting fields lie fallow.
   4. Remove CO_2 from smokestacks and pump it deep underground, or inject it into the deep ocean. There are several technical problems with this approach at present.

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21-22 How Can Governments Reduce the Threat of Global Warming? Use Sticks and Carrots

A. Governments can tax emissions and energy use, increase subsidies and provide tax breaks for saving energy, but decrease subsidies and tax breaks for using fossil fuels. Three possible strategies for promoting solutions to global warming are as follows:
   1. Phase in carbon taxes on fossil fuel use, and at the same time decrease taxes on income, labour, and profits to offset the consumption taxes.
   2. Increase government subsidies for energy efficiency and carbon-free renewable-energy technologies.
   3. Transfer knowledge from developed countries to developing countries.

21-23 How Can We Use the Marketplace to Reduce or Prevent Greenhouse Gas Emissions? Emissions Trading

A. Establishment of a global emissions trading program could help reduce greenhouse gas emissions.
   1. Agree to global and national limits on greenhouse gas emissions and sell or trade greenhouse gas permits in the marketplace.
   2. Credits could be earned by
      a. improving energy efficiency,
      b. switching energy sources,
      c. adopting conservation farming practices,
      d. reforesting land, or
      e. injecting CO_2 into the deep ocean or secure underground reservoirs.
   3. Participants who produce fewer emissions than what they are allowed could sell some of their credits to other participants.
   4. There are problems with monitoring compliance, and a combination of approaches is necessary.

21-24 Can We Afford to Reduce the Threat of Global Warming? Not Acting Will Probably Cost More

A. It will probably cost less to help slow and adapt to global warming now than to deal with its harmful effects later.
   1. Some economists indicate the costs of reducing CO_2 emissions exceed the benefits; however,
      a. they do not take into account the huge cost savings once strategies are implemented (e.g., improved energy efficiency), and
      b. they underestimate the ability of the marketplace to act rapidly when money is to be made.
   2. By 2050, costs related to global warming could reach $300 billion annually.
   3. Some studies indicate that implementing conservation strategies would boost global and national economies.

21-25 What Was the Kyoto Protocol? A Controversial International Agreement

A. Getting countries to agree on reducing their greenhouse gas emissions is difficult.
B. The Kyoto Protocol, developed in 1997, required 39 developed countries to cut CO_2, CH_4, and N_2O emissions to 5.2% below 1990 levels by the year 2012.
   1. Developing countries did not have to make cuts until a later date.

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2. Many climate analysts felt that the Kyoto Protocol was an important first step in cutting emissions.
    a. Several NGOs claimed that the Kyoto Protocol would save money, reduce pollution, improve health, and create new jobs.
3. The United States did not support the Kyoto Protocol.
    a. President George Bush withdrew from Kyoto in 2001. He gave the following reasons.
        1) It was too expensive.
        2) Developing countries did not have to cut emissions.
        3) The U.S. economy would be hurt.
        4) Americans would lose jobs.
    b. Many scientists and world leaders protested his decisions.
    c. Bush opted for a "made in the U.S.A." solution. This plan involved
        1) reducing power plant emissions and
        2) business incentives to encourage voluntary GHG emission reductions (reductions of 4.5% over 10 years).
    d. Critics have argued that Bush was protecting the fossil fuel industry, and his plan for emission reductions would not match Kyoto Protocol reductions.

21-26 What is the Paris Agreement? All Aboard

A. Nearly 200 countries, rich and poor, will together aim to keep the temperature increase to well below 2°C. They will publicly report on their progress every five year.
    1. The successor to the Kyoto Protocol, the Paris Agreement establishes the goal of limiting temperature increases to "well below" 2°C above pre-industrial levels, while also striving for a more ambitious 1.5-degree limit.
    2. It aims to avoid the Kyoto Protocol's more controversial features.
    3. The Paris Agreement commits all participating nations (not just developed countries) to prepare and implement their own nationally determined greenhouse gas reduction targets.

21-27 What Is Canada's Position on the Kyoto Protocol and Climate Change? Inconsistent

A. Canada's stance on the Kyoto Protocol has varied from extreme support to opposition.
    1. In 1988 Prime Minister Brian Mulroney and the Norwegian Prime Minister, Gro Harlem Bruntland, co-hosted the Toronto Conference on the Changing Atmosphere.
        a. Global warming was identified as a major threat.
        b. They called for a 20% reduction in GHGs by 2005.
    2. In 1992, the Earth Summit was held in Rio de Janeiro, Brazil ("the Rio Convention").
        a. A Canadian, Maurice Strong, hosted it.
        b. Canada and the United States were two of many countries that ratified an agreement to stabilize 1990 emissions by 2000.
    3. In 1997, at the Kyoto Convention in Japan, participating countries decided that the targets originally set at Rio were too weak.
        a. The new target aimed to reduce 1990 GHG emissions, by 5%, between 2008 and 2012.
        b. Each country had a target. Canada agreed to a 6% reduction and the United States to a 7% reduction.
        c. Both Canada and the United States signed the Kyoto Protocol.

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4. Prime Minister Jean Chrétien ratified the Kyoto Protocol in 2002.
5. In December of 2005, Canada hosted the United Nations Climate Change Conference in Montreal.
   a. Prime Minister Paul Martin and Environment Minister Stéphane Dion were in full support.
   b. Kyoto's 159 members strengthened the protocol and started negotiations for GHG emissions after 2012.
6. Canada has made little progress in reducing GHG emissions. Canada's 2004 emissions were 34% higher than the Kyoto Protocol target.
7. In 2006, Prime Minister Stephen Harper announced that the government was not in favour of the Kyoto Protocol.
   a. He talked about a "made in Canada" solution.
   b. The Clean Air Act provided the government with the authority to regulate air pollutants and greenhouse gases, but it didn't impose immediate deadlines or targets.
   c. Canada formally withdrew from the Kyoto Protocol in December 2011, amid strong criticism from the international community, as Canada would not be able to meet its Kyoto commitments.
   d. In 2012 Canada joined a voluntary international effort focusing on the reduction of short-lived climate pollutants (SLCPs), including methane and black carbon.
8. In November 2015, Prime Minister Justin Trudeau took office, having campaigned on a promise to improve Canada's climate change record. Prime Minister Trudeau stated that he intended to have a new national plan in place by the spring of 2016.

21-28 What Are Some Countries, Businesses, and Cities Doing to Help Delay Global Warming? Good News

A. Many countries, companies, and cities are reducing GHG emissions by improving energy efficiency and increasing their use of carbon-free renewable energy.
   1. By 2000, Great Britain reduced its GHG emissions to 1990 levels, well ahead of Kyoto targets. More natural gas was used, instead of coal.
   2. China is taking steps to reduce its dependence on coal by increasing the energy efficiency of its industries and by pursing the development of other energy sources (such as hydro) and fusion. As well, China is becoming a world leader at developing solar cells, wind turbines, high-tech batteries, and electric cars.
   3. Some major global companies have established targets to reduce their 1990 GHG emissions by 10 to 65% by 2010.
   4. Many cities around the world have introduced programs to reduce GHG emission.

21-29 How Can We Prepare for Global Warming? Get Ready for Change

A. A growing number of countries and cities are looking for ways to cope with the harmful effects of climate change.
   1. Estimates are that current emissions of greenhouse gases must be cut by at least 40% by 2050 to maintain a likely temperature increase relative to 1850–1900 of no more than 2°C.
   2. This means that some increase is already "locked-in." Lesser reduction lowers the chances of achieving the 2°C goal.
   3. For political and economic reasons, such a reduction is extremely unlikely.
   4. We should prepare for the effects of long-term atmospheric warming.

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21-30 Why Are Global Warming and Climate Change Such Difficult Problems to Deal With? A Complex, Long-Term, and Controversial Challenge

A. Global warming and climate changes are hard to deal with because they have many causes, the effects are long-term and uneven, and there is controversy over solutions.
   1. There are many complex and still poorly understood causes and effects of global warming.
   2. These are long-term problems.
   3. Ethical questions need to be asked, such as, How much are we willing to change or sacrifice now for benefits that may not occur in our lifetime, but could benefit our children and grandchildren?
   4. We do not know exactly where the harmful and beneficial effects of climate change will occur.
   5. Reducing greenhouse gas emissions will require an international response.

21-31 What Is the Threat from Ozone Depletion? A Clear Danger

A. Less ozone in the stratosphere will allow more harmful UV radiation to reach the Earth's surface. The overwhelming consensus of researchers is that ozone depletion is a serious threat to humans, other animals, and some of the primary producers that support the Earth's food.

21-32 What Causes Ozone Depletion? From Dream Chemicals to Nightmare Chemicals

A. Widespread use of a number of useful but long-lived chemicals has reduced ozone levels in the stratosphere.
   1. The first chlorofluorocarbon (CFC) was discovered in 1930, and chemists developed a family of useful CFCs. Freons are the most widely used of these.
   2. They had many uses and were popular because they were inexpensive to manufacture and seemed to have many ideal characteristics.
   3. In 1974, chemists Rowland and Molina found that CFCs were decreasing the average concentration of ozone in the stratosphere.
   4. Four major conclusions came from their research.
      a. CFCs remain in the atmosphere because they are insoluble in water and chemically unreactive.
      b. Within 11 to 20 years, these chemicals reach the stratosphere, mostly by convection currents and turbulent mixing of air.
      c. CFC molecules break down under the influence of high-energy UV radiation. Highly reactive chlorine fluorine, bromine, and iodine are released, causing ozone to be broken down faster than it forms.
      d. These CFC molecules can last in the stratosphere for 65 to 385 years.
   5. In 1988, after 14 years of delay tactics, the CFC industry acknowledged that CFCs were depleting the ozone and agreed to stop manufacturing them.
   6. Rowland and Molina received the Nobel Prize in chemistry for their work.

21-33 What Other Chemicals Deplete Stratospheric Ozone? More Culprits

A. A number of chemicals can end up in the stratosphere and deplete ozone there for up to several hundred years.
   1. These chemicals include halons and hydrobromofluorocarbons (HBFCs) (used in fire extinguishers); methyl bromide (a widely used fumigant); hydrogen chloride (emitted

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directly into the stratosphere by solid rocket boosters such as those once used for the Space Shuttle); and cleaning solvents such as carbon tetrachloride, methyl chloroform, n-propyl bromide, and hexachloro-butadiene.

21-3 What Happens to Ozone Levels Over the Earth's Poles Each Year? Levels Drop Each Winter and Spring

A. During four months of each year, up to half of the ozone in the stratosphere over Antarctica is depleted.
   1. Ozone loss is often called the ozone hole, but it is actually ozone thinning.
   2. The total area of stratosphere that suffers from ozone thinning varies from year to year. In 2006, the area of thinning was the largest size ever (Figure 21-26).
   3. The primary culprits are CFCs and other ozone-depleting compounds (ODCs).
   4. Every winter in Antarctica, a polar vortex, a swirling mass of very cold air, forms.
      a. It is isolated from the rest of the atmosphere until the sun returns in spring.
      b. Water droplets in the polar vortex form tiny ice crystals.
      c. The surfaces of the ice crystals in this mass collect CFCs and other ODCs, setting up conditions for the formation of ClO (the molecule most responsible for seasonal loss of ozone).
      d. As sunlight returns to Antarctica in October, the light stimulates the formation of ClO molecules.
      e. Within a matter of weeks the ozone, on average, is reduced by 40 to 50%.
   5. In 1988, scientists discovered ozone depletion over the Arctic.
      a. It was similar to, but less severe than, ozone loss in Antarctica. (11 to 38%).
      b. It occurred during the Arctic spring and early summer.
      c. It is unlikely that the Arctic thinning will be as severe as that over Antarctica, but it is predicted that the worst ozone thinning will occur between 2010 and 2019.
      d. Arctic ozone thinning is problematic because
         1) people living there will have increased UV exposure, and
         2) Arctic ecosystems, already exposed to fat-soluble chemicals in food chains, will be further stressed.

21-2 Why Should We Be Worried about Ozone Depletion? Life in the Ultraviolet Zone

A. Increased UV radiation reaching the Earth's surface from ozone depletion is harmful to human health, crops, forests, animals, and materials. Figure 21-27 lists the effects of ozone depletion.

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21-3 What Cancer Are You Most Likely to Get? Look in the Mirror

A. Exposure to UV radiation is a major cause of skin cancers.
   1. The primary cause of squamous cell and basal cell skin cancers is years of exposure to UV-B radiation. Fortunately, 90 to 95% of these cancers can be cured if detected early enough.
   2. Malignant melanoma is a third type of skin cancer that may occur anywhere on the body. It kills a fourth of its victims (most under the age of 40) within five years.
   3. Women who use tanning parlours at least once a month increase their chances of developing melanoma by 55%.
   4. Evidence suggests that 90% of sunlight's melanoma-causing effect may come from exposure to UV-A (not blocked by window glass).
   5. Caucasians are most susceptible to melanomas.

21-4 How Can We Protect the Ozone Layer? Say No

A. To reduce ozone depletion we must stop producing ozone-depleting chemicals.
   1. If we immediately stop producing all ozone-depleting chemicals, it will take 50 years for the ozone layer to return to 1980 levels and about 100 years to return to pre-1950 levels.
   2. The goal of the 1987 Montreal Protocol was to cut emissions of CFCs by about 35% between 1989 and 2000.
   3. Representatives met again in 1990 and 1992 and adopted the Copenhagen Protocol, an amendment that accelerated the phase out of key ozone-depleting chemicals.
   4. One hundred and eighty-seven countries have now signed these agreements.
   5. Since ozone-depleting chemicals also function as greenhouse gases, the success of the Montreal Protocol has yielded a net reduction of planet-warming gases equivalent to eliminating 25 billion tonnes of CO_2.
   6. The ozone protocols set an important precedent for global cooperation and action to avert potential global disaster by using prevention to solve a serious environmental problem.

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