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## **ABSTRACT**

### **STRATOSPHERIC OZONE LAYER DEPLETION: A COMPUTER AIDED CASE STUDY**

**by  
James M. Lipuma**

In industries today, there is a desire to stop pollution before it starts, through the process of pollution prevention. Unfortunately, many university level students are not exposed to the thinking process involved in environmental problem solving early enough in their academic career, if they are exposed to it at all. The goal of this thesis is to develop and to evaluate an interdisciplinary case-study about the depletion of the stratospheric ozone layer by chlorofluorocarbons (CFCs). This case-study will be used to teach first year chemistry students about environmental problem solving.

The case study was assembled from existing literature according to principles derived from environmental texts. The written case study was evaluated first by a panel of four industry experts. The case study was then transformed into a computerized teaching tool using a Hypertext Markup Language (HTML) editor. The computer tool was then evaluated by a separate panel of experts comprised of three industry experts, and three university professors. The professors were from the fields of chemistry, economics, and history. Both the economics and history professors were familiar with the field of environmental policy. This mix of disciplines allowed for a balanced evaluation of the interdisciplinary teaching tool. Finally, the experts' comments were incorporated into the final version of the teaching tool.

**STRATOSPHERIC OZONE LAYER DEPLETION:  
A COMPUTER AIDED CASE STUDY**

by  
**James M. Lipuma**

**A Thesis  
Submitted to the Faculty of  
New Jersey Institute of Technology  
in Partial Fulfillment of the Requirements for the Degree of  
Master of Science in Environmental Policy**

**Department of Humanities and Social Sciences**

**May 1996**

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**APPROVAL PAGE**

**STRATOSPHERIC OZONE LAYER DEPLETION:  
A COMPUTER AIDED CASE STUDY**

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This thesis is dedicated to my family  
without whose help, understanding, and support  
this work would not have been possible.



## ACKNOWLEDGMENT

The author wishes to thank all those who have assisted with the research, especially his advisor Dr. Norbert Elliot. Professor Elliot provided inspiration, guidance, and direction as well as invaluable help throughout the research process.

Special thanks to Dr. Daniel Watts and Dr. John Opie for serving as members of the committee and assisting in the refinement of the thesis.

The author is grateful to the National Science Foundation (NSF) for their funding through a Technology Reinvestment Project (TRP) grant, award number CTS-9413104, to the New Jersey Institute of Technology. Without this funding, the research would not have been possible.

Finally, a thanks to all those who assisted with the research by providing expert criticism which helped improve the overall quality of the research.

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**CHAPTER 1**  
**RESEARCHING AND WRITING**  
**THE CASE STUDY**

**1.1 Introduction**

For more than fifty years, the class of chemicals known as chlorofluorocarbons (CFCs) was thought to be completely safe. These chemicals were nonreactive and thought to be non-threatening to human health. In 1974, however, F. Sherwood Rowland and Mario Molina postulated that CFCs cause the depletion of the stratospheric ozone layer and thus posed a great threat to human life on earth. The ozone layer acts as a shield protecting the surface of the earth from harmful ultraviolet radiation. As the shield thins or disappears, more of the harmful radiation reaches the surface of the earth causing many problems. These problems include crop damage, skin cancer, cataracts, and weakened immune response to disease. Though the problems caused by a depleted ozone layer were not debated, the idea that CFCs contributed to the depletion of ozone was highly controversial. For more than ten years, scientists worked to validate or refute the theory which had little evidence on the earth's surface.

By the beginning of the 1980's, international concerns over the depletion of the ozone layer began to grow. The Vienna Convention for the Protection of the Ozone Layer held in 1985 was the first international meeting to focus on the problem of stratospheric ozone depletion. The appearance of the Antarctic ozone hole lent credence to the Rowland and Molina theory and increased global concerns about chemicals which might be harmful to the ozone layer. In 1987, the governments of the world agreed to

the Montreal Protocol, the first environmental treaty dealing with ozone depleting substances.

Since that time, two amendments have been ratified which increase the pace of removal of the CFCs from the world environment. At the same time, companies such as DuPont have worked to find viable alternatives for CFCs which are safe for the environment and cost effective. Many industries have begun finding ways to eliminate the need for CFCs all-together--thus reducing the demand for these chemicals. Under the provisions of the Montreal Protocol and its amendments, within the next twenty years CFCs will be banned from production and eventually replaced entirely by chemicals which do not harm the stratospheric ozone layer.

This thesis will use the story of CFCs to teach first year chemistry students about the fundamentals of inorganic chemistry and atmospheric chemistry while demonstrating to the students some very important lessons about the nature of environmental problems and their solutions. Since the facts about CFCs have been debated for so long and the case-study is so well developed, it is possible to present a well-balanced and relatively complete picture of this important topic in the history of environmental policy studies.

During the preparation of this thesis, a great deal of information was gathered about CFCs, chemistry, politics, history, and economics. These subjects all directly relate to the case-study. However, it was necessary to also investigate the concepts used by environmental educators as they try to instruct students about environmental problems. Only with this type of understanding could a truly balanced and effective case-



study be produced. The final product of this thesis will be a computerized teaching tool for use on the internet or in classrooms around the nation.

## **1.2 Related Literature**

When the first human understood that there was a relation between the actions of humans and the effects to the environment, ecology was born. Though it took many thousands of years to be recognized, this important science was practiced throughout history.

Scientists made observations, took readings, and postulated theories about the inner workings of the natural world and tried to develop rules for human interactions with that world. Though the elements of respect and concern may not have been evident until much later, even from the beginning, a sense of respect and awe of nature can be seen.

### **1.2.1 Fundamentals of Ecology**

In his book *Fundamentals of Ecology*, Eugene P. Odum writes about the concept that ecology existed for many thousands of years before it was formalized into a science. He continues along this line of reasoning by describing the beginnings of the formalization and the early inception of this new and vital science. Human interaction and comprehension of its environment is vital to survival. Odum is often credited with the wide acceptance of the field of ecology as a science as well as giving the fledgling field a great deal of definition. In his own words, “To many, ecology now stands for the total of man and environment.”(Odum 1971, 4)

This broad definition does not suffice, however. Though there are unifying principles which govern the science, boundaries must be drawn to delineate the subject

matter. Though a wide range of subjects can fall into the realm of ecology, Odum points out that, “one cannot study eagles by the same methods used to study bacteria.” (Odum 1971, 4). By this, Odum suggests that though the fields of study within the science of ecology are related, it is necessary to make separations. The many disciplines that develop can build on the information from other areas.

This distinction between popular belief and academic understanding is important to ecology and all environmental science. Building upon Odum’s ideas, many new fields of study appeared under the umbrella of ecology. Links between the new science and many of the older more established sciences were forged. Today, the fields of environmental studies, environmental science, and environmental engineering have joined ecology at the university level. From a humble beginning, the idea of environmental sciences has blossomed.

### **1.2.2 Aldo Leopold’s Land Ethic**

Before there was a well-established science of ecology, Aldo Leopold spoke about concern for our environment in the form of a Land Ethic. In 1949, *A Sand County Almanac* was published posthumously. Several years later, in 1953, the Round River essays were added to the text making it one of the most important environmental books of its time. In the book, Leopold writes of many things including beauty of nature, the lack of understanding many people have of the world around them, and the high and unjustified cost that must be paid for progress.

Within the book, Leopold speaks of the Round River, which is an elegant metaphor for the biosphere. The water of the river is the energy of life which flows

through the biotic community. Humans are said to be riding logs upon the Round River.

Leopold uses the story of the river to bring out his point of conservation. He says that

“From our tenderest years, we are fed with facts about the soils, floras, and faunas that comprise the channel of the Round River, (biology) about their origins in time, (geology and evolution) about the techniques of exploring them, (engineering and agriculture).”

(Leopold, 189) In Leopold’s eyes, this is a narrow and even dangerous view. The expertise of science does not provide enough information about the failing of humans and their relations to nature.

To accomplish a workable interaction with nature, Leopold feels humans must work perpendicularly to the current movements of science. “This calls for a reversal of specialization; instead of learning more and more about less and less, we must learn more and more about the whole biotic landscape.”(Leopold 1966, 189) The environmental sciences have attempted to do this. Unfortunately, they are still a science and fall into the rigors of that field. Too often, scientists fall into the trap of over-analysis and become lost in the minutia of a problem. The statements made by Leopold suggest that it is necessary to step back and look at the problem in a more interdisciplinary and holistic way.

Later in the same book, the Land Ethic is discussed. Leopold puts forth the idea that “All ethics so far evolved rest upon a single premise; that the individual is a member of a community of interdependent parts.” (Leopold 1966, 239) He continues later to say, “The land ethic simply enlarges the boundaries of the community to include soils, waters, plants, and animals, or collectively, the land.”(Leopold 1966, 239)

The ideas put forth by *A Sand County Almanac* were meant to broaden the minds of those reading the text. Leopold was trying to show that human needs were tied to the needs of the rest of the biotic community. Though he only spoke of a land ethic, his ideas could be expanded to cover the entire biosphere.

### **1.2.3 Small Is Beautiful**

Twenty years after the first publication of the combined essays of Aldo Leopold, another landmark book was published. *Small Is Beautiful: Economics as if People Mattered* by E. F. Schumacher made an impact on environmental thought when it was published in 1973. Rather than talk of science or ethics, Schumacher's book was centered on economics, but did not limit itself to that topic. In the study, Schumacher discusses economics, philosophy, technology, as well as many other fields which are all interrelated to economic development and growth. He attributes this development to humans not nature. Though natural resources are utilized, it is human thought, ingenuity, and work which allows it to be utilized. The learning and building of knowledge, in Schumacher's mind, is what allows for the wealth of human development. This leads him to say, "In a very real sense, therefore, we can say that education is the most vital of all resources." (Schumacher 1973, 60)

Knowing that education is a vital link in development is important, but not enough. Schumacher continues his discussion about education by discussing two types of problems--convergent and divergent. Convergent problems can be solved with reason while divergent ones cannot. Too often, however, humans try to solve divergent problems by reducing them to easier convergent problems which can be handled with

reason. This approach does not work according to Schumacher. “The true problems of living are. . . divergent problems and have no solutions in the ordinary sense of the word. They demand of man not merely the employment of his reasoning powers, but the commitment of his whole personality.” (Schumacher 1973, 77) This means that humans cannot simply rely on science to provide easy answers to difficult questions. Instead, humans must work together to find compromises and just solutions to these difficult divergent problems which arise.

Taking this discussion to a higher level, it becomes the role of educators to teach students to look at problems in a more advanced way. No longer should everything be reduced to simplest terms. No longer can everything have a right and a wrong answer. No longer will there always be one right answer. Finally and most important, no longer will there be problems which science can solve with a simple fix of technology and intellectual endeavor. Environmental problems call for humans to work together to reach a consensus and find a solution which works. Human thought and interaction will be the way complex issues can be resolved rather than through the sheer force of new and more advanced technologies.

#### **1.2.4 The Limits to Growth**

Besides the problems of overly specialized education and reductionist thinking brought out by Schumacher, the problem of perspective must also be addressed. Donella Meadows tied many of the problems of the world to population and human perspective in *Limits to Growth: A Report to the Club of Rome's Project on the Predicament of Mankind*. Many of the problems relate back to human perspectives of the world.

Problems which exist in the future or seem to affect others alone do not have the impact of immediate endangerment of life, or property. According to Meadows, “The majority of the world’s people are concerned with matters which affect only family or friends over a short period of time. Others look farther ahead in time or over a larger area, a city or a nation. Only a very few people have a global perspective that extends far into the future.” (Meadows 1972, 4) The problem arises when people are faced with a problem which is global in nature and the impact of which will not be felt for several years. Too often, a person must resolve more local and pressing problems before attention can be turned to large problems. The difficulty arises when no one is willing to deal with the global problems which confront everyone. This idea of a global perspective becomes important when looking at the impact of society upon the natural world. Unless a problem is identified as critical, resources will not be spent and time will not be invested to find a solution.

### **1.2.5 Earth in the Balance**

More recently, Vice-President Al Gore’s book, *Earth in the Balance*, highlights the interconnectedness of many global environmental problems. His book examines and explains many worldwide environmental problems as well as the cycles of life that interact throughout the biosphere. The text describes the relationships between many environmental problems throughout recorded history. By explaining what has happened in the past, he points out trends in the past as well as the present. These trends are extrapolated out into the future to show what might happen. With ease, predictions about the dire consequences of human actions can be made and supported.

*Earth in the Balance* also shows how a regional solution to global problems would be difficult. Though each individual can work tirelessly, communities of individuals must come together to make a global solution work. Since every person living today is part of the same biosphere, the actions of any one cannot be taken separately from the actions of the rest. This idea of a global community is a vital part of any environmental problems solving model. Without this type of perspective, the solutions to global problems will remain beyond the reach of those trying to grasp them.

The books spoken of above are but a few of the many great works of environmental literature that have been published in the past. These few, however, provide insight into the foundation of environmental thought that exists today. These texts provided a great deal of useful information and insight into the technological problems and challenges of our world as well. All of these books spoke of some type of education, learning, or knowledge either indirectly, by making references or directly, through deliberate statements. Every one of these texts put forth education as the hope for the environment of the planet.

The North American Association of Environmental Education (NAAEE) is working towards that goal of a sustainable and productive future. During the opening ceremonies of a NAAEE conference, Arthur B. Sacks made a speech about the direction of environmental education in North America. In it he said, "If we are to optimize environmental education's affect to advance humankind to a sustainable future, we must find new and better ways to cooperate among ourselves as well as with our brethren and sisters within the decision-making community." (Sacks 1986, 6). This idea of

cooperation is vital to any solution. Without forethought and cooperation by large numbers of individuals, solutions may be impossible. Though the books already mentioned serve as an excellent primer on the problems of the environment and ways environmental education can be accomplished, one book still remains.

### **1.2.6 Environmental Education Curriculum Planning**

One of the most useful texts for understanding principles of environmental education is the *Guide to Curriculum Planning in Environmental Education* written in 1985 by David C. Engleson. This book provides a great deal of insight into how environmental concern can be instilled into students and taught so that it is carried away from the classroom into the everyday lives of those who are being taught. The author writes of infusing an environmental ethic into an existing curriculum. Rather than trying to add a class, an existing class must be given an environmental component. In this way, the students are learning about preserving the integrity of the environment as they learn about the subjects which they will use during their lives.

From my research into environmental education, four central ideas became apparent. First, the ideal of environmental concern must be infused into an existing curriculum. Teaching these types of ideals without a context is difficult and often does not carry into the fields where it is most needed. Second, the treatment of the material should be diverse and interdisciplinary to allow for the greatest understanding and applicability. Third, the information being taught needs to be accessible by the students. To accomplish this accessibility, the material should be presented in an interesting and thought provoking way. Over-technical language should be used only when unavoidably



necessary. Fourth, the material must be tied to the everyday lives of the students through examples and real-world explanations.

Having completed the research into environmental education, our research team-- Daniel Watts, Norbert Elliot, and I decided that a case study dealing with the depletion of the stratospheric ozone layer by CFCs would be infused into a first year chemistry curriculum. (Rosengarten, Lipuma, and Elliot 1995; Elliot and Watts, 1995) The ozone case study would be used to help teach environmental problem solving and concern. The ozone case study was seen as a mature subject, making it ideal as an overview and preliminary teaching tool. In this context, mature means that the issues surrounding the problem have gone through several phases. At this point in time, debate about the scientific facts, uncertainties, and global acceptance have been largely resolved and some consensus about the controversial issues have been reached by the parties involved. Also, the actions taken by the world community serve as a positive example of how environmental problems can be debated, resolved, and remedied.

### **1.2.7 Chemistry in Context**

Once the topic of the case study was chosen, several sources were consulted to gather enough information to form a complete picture of the stratospheric ozone layer depletion problem caused by CFCs. Though the case study was being infused into a chemistry curriculum, it was important to know the economics, politics and history of the problem. Also, it was important to keep the entire case study simple enough to be interesting and understandable but complex enough to provide a complete picture of the problems and their solutions.

The first text used to bridge the gap between the existing knowledge about the stratospheric ozone layer depletion problem and the literature gathered about environmental education was *Chemistry In Context: Applying Chemistry To Society*. (1994) This textbook was developed by the American Chemistry Society (ACS) to help teach both high school and college students about chemistry. Instead of dividing the curriculum into the sections traditionally used to teach chemistry such as gas laws and the kinetic theory, conservation of mass and energy, periodic behavior of the elements, or atoms, molecules, and ions, the ACS text used a case study approach to teach related topics in an interdisciplinary context. Related groups of fundamental chemical principles were introduced using a relevant current event or article. Each case study interweaves political, economic, social and international issues to build a complete picture. Though the chemistry is stressed, the students are shown how it applies to everyday life and given a broader and deeper educational experience.

Chapter two of the text contains a case study about the stratospheric ozone layer depletion problem. It provides an example of how some of the concepts which needed to be integrated into the case study could be addressed. It gave insight into how to infuse chemistry with other issues as well as make it interesting. Also, the text demonstrated that graphics could be used to augment the students' learning without distracting the student. Overall, the ACS text was a good launching point for the investigation into the material which would be used to build the stratospheric ozone layer depletion problem case study.

## 1.3 Building the Case Study

### 1.3.1 The Process of Designing the Case Study

Having examined the literature, it was time to construct the stratospheric ozone layer depletion case study. This process would require four steps, some of which occurred simultaneously. When building a case-study, one must draw upon many fields and information sources. The existing chemistry curriculum served as the starting point for the development of the ozone case study. To help place these principles into a real-world context, a historical overview precedes the body of the text. The information about basic chemistry was supplemented by enough atmospheric chemistry to allow the students to understand the problem that CFCs created in the atmosphere. Along with these principles, political and economic factors are discussed to help broaden the case study and make it easier for students to understand. Decisions which influenced the proliferation of CFCs to the industries of the world and eventually helped restrict and replace them are included to give a truly interdisciplinary and balanced view of the problem and its solutions.

As has already been stated, the first step in developing the stratospheric ozone layer depletion case study was to do general research into the area of environmental education and the problem of stratospheric ozone layer depletion. Once this had begun, it was necessary for me to attend several first year chemistry classes. This second step would allow for a better understanding of what material was being taught and how the case study could be integrated into the curriculum. The third step in the writing process was to actually research the stratospheric ozone layer depletion problem. Once these

three steps were completed, the case study was written. The last step in the process was to have an independent group of industry experts assess the written case study.

### 1.3.2 Attending Chemistry Classes

It was necessary to attend first year chemistry classes at the New Jersey Institute of Technology (NJIT) in order to gain a better understanding of what is taught in first year chemistry classes. Before sitting in on all the chemistry classes offered, the author consulted *A Practical Guide to Knowledge Acquisition* (1991) by A. Carlise Scott et al. This text helped to identify how to approach the research and interview process which would be necessary to gather the pertinent information. It was suggested that a diverse scope of good and bad classes should be attended at first to give the interviewer an understanding of the range that exists. Slowly, the number of classes could be narrowed until only the best and most applicable would be selected.

During the process of selection, the author attended four different chemistry classes--one honors high school class, and three first year honors classes. The author observed the high school class to gain insight into the skills that the incoming first year students might have as they began the college level courses. This investigation was purely informational. The two college level chemistry courses both covered the same material but each had its own pace and scheduling. It became quickly apparent that the different teaching styles weighed heavily in the content and rigor of the course. One course met for only a portion of the period and the students were asked to keep up with the reading outside of class. The teaching seemed to be less intensive and relied more on students being able to educate themselves.

The second college level class was taught by a recipient of the Excellence in Teaching Award. This class was much more in-depth and structured. It utilized multimedia presentations along with lectures and demonstrations to teach the students. It became quickly clear that the material being presented in this class was being absorbed more readily by the students. This class served as a better representative model for use in the case study. As a result of this investigation, the author spent the semester observing the class to determine how all ranges of students could be better taught. By speaking with the professor and observing the class structure, an overall feeling for how an integrated interdisciplinary case study approach could be used to teach was developed. With this understanding, the case study material was gathered.

### **1.3.3 Researching the Stratospheric Ozone Layer Depletion Problem**

The gathering of information began with two books about the problem of CFCs and their relation to the ozone layer. The two books which served as the initial starting point for the investigation were *Between Earth And Sky* (1993) by Seth Cagin and Philip Dray and *The Ozone Crisis: The 15 Year Evolution of a Sudden Global Emergency* (1989) by Sharon L. Roan. *Between Earth And Sky* provides an excellent overview of the development of CFCs from the mid 1800s until the mid 1980s. *The Ozone Crisis*, on the other hand, gives a more in-depth description of the process of discovery surrounding the Rowland and Molina ozone depletion theory. Together these two books provided an understanding of the ozone depletion problem that would allow me to continue my research in order to create a balanced case study.

Knowing the material related to the problem, the next step was to link this information to a chemistry curriculum. After consulting teachers, attending first year chemistry classes and reading *Chemical Principles* (1984) by Richard E. Dickerson et al., the basic chemical principles which would be included were chosen and built into the case study. Since the case study was to be used near the beginning of the first year chemistry classes, basic information about atoms, bonding, the periodic table, the ideal gas laws, and other fundamental chemistry was placed near the beginning of the narrative. This material was easily described but still needed to be linked to the material concerning ozone depleting chemicals.

Seeing a need for an overall unifying force, a historical timeline was constructed next. By building the case study along this timeline, it would be possible to give a sense of flow and movement to the events and principles being discussed. The initial discovery of oxygen by Leonardo Divinci in the fifteenth century was chosen as an appropriate beginning point. It was both relevant and far enough in the past to precede any discoveries which were going to be discussed in the case study. From that point forward, the discoveries and important dates derived from the three books mentioned above were placed on the timeline. Unfortunately, there were some gaps in the timeline and in the information being provided to students.

In order to tie the first and second parts together, it was necessary to discuss atmospheric chemistry. This discussion was also necessary to allow students to better understand the problem that CFCs were causing in the stratosphere. *Environmental Chemistry* (1994) by Stanley Manahan along with information from NASA's Ozone page

on the World Wide Web provided enough information to build the atmospheric chemistry portion of the case study.

Having built the chemistry and atmospheric chemistry into the case study, it was now time to integrate politics and economics. These subjects would also help to fill in the holes in the overview. Several texts were used to provide the pieces of information used in the case study. Several texts supplemented those already mentioned earlier. Many times, the economics and politics were difficult to extract from one another. Each played an integral part in decisions about the other. The major works used to build these parts of the case study are: *Economics and the Environment* (1995) by Eban S. Goodstein, *Ozone Layer Protection: Country Incremental Costs* (1995) by Kenneth King and Mohan Munasinghe, "Management of Transnational Commons: Coordination, Publicness, and Treaty Formation," (1995) by Todd Sandler and Keith Sargent, and *The Environmental Law Handbook* (1995) by Thomas F. P. Sullivan. With the addition of the information in these books and articles, most of the case study was complete.

The final part which remained was the discussion of possible alternatives to CFCs which companies such as DuPont were developing. The text *Taking Sides: Clashing Views on Controversial Environmental Issues* (1993) edited by Theodore D. Godfarb provided information about the work ongoing at DuPont. Articles such as Peter Fairley's "Hydrocarbon Options Emerge," in *Chemical Week* provided more scientific information on possible alternatives to CFCs. Also, articles from News wires on the World Wide Web were used for the continuing progress and most recent entries on the timeline and in the case study.

Before moving too far into the investigation, a search of the World Wide Web was conducted to find as many useful sources and diverse views as possible. Most of the sources, however, were incomplete and not useful. Some, such as the ozone page run by NASA, did provide a useful discussion of small parts of the problem. Overall the material found on the internet did not prove to be unique or irreplaceable. The information provided by these sources could be located in hard copy in libraries. One notable exception must be made for the news articles and other current events which the internet provided. Both the ease of access and the completeness of the sources helped greatly in the construction of the case study. Some graphics were also taken from the internet but most were scanned in or created by the author.

Though it was necessary to continually look for new sources, the internet search signaled the end of the major research effort. With the research completed, it was now time to write the actual case study.

#### **1.3.4 Writing the Stratospheric Ozone Layer Depletion Problem**

To facilitate computerization, completeness, and coherency, the case study was first written using Microsoft Word. Using the sources listed above, the narrative for the case study was composed. The historical overview in the form of a timeline was also created as a separate Word document. Graphics were included in the narrative to closely replicate what would appear in the final computerized case study. The entire narrative was broken into seventeen sections each given a header similar to a page number, such as Page 1 of 17. When the writing process was complete, the entire narrative and timeline package was forty eight pages long.



With all the information written into a continuous coherent integrated case study, the case study was complete. After checking to ensure there were no large gaps in knowledge or incorrect statements, the case study was ready to be assessed by industrial experts.

### **1.3.5 Assessing the Initial Design of the Case Study**

During the development of the written case study, it was necessary to survey a panel of experts to determine if the written case study was being built properly. With the assistance of an independent industry consultant, a panel of four experts from AT&T Bell Labs was assembled. The experts asked to remain anonymous but were willing to provide their qualifications and answer a survey. The description of the experts comprising the panel are given below.

Expert #1 is a male, age 41, who holds a Ph.D. in Chemistry from the University of Michigan. He is a distinguished member of the technical staff in the Environmental Sciences Research Dept. at AT&T Bell Labs. His specific area of research has been to identify environmentally-safe alternatives to some of AT&T's current processes, including the recommendation of non-CFC producing chemicals. He has written and presented over 20 papers in this area, and has lectured at several high schools to educate students about the environmental concerns in industry.

Expert #2 is a male, age 53, who holds a Ph.D. in Chemistry. He is a distinguished member of the technical staff in the Chemical Analysis Research Department of AT&T Bell Labs. He has been working within AT&T Bell Labs for over twenty years specifically focusing on issues involving atmospheric chemistry. During

his tenure at AT&T, he has authored three books and over fifty publications dealing with this area.

Expert #3 is a male, age 46, who holds a Ph.D. in Chemical Engineering from the University of California at Berkeley. He holds a management position in the Chemical Engineering Research Department at AT&T Bell Labs. As part of his duties, he oversees sixteen staff members. These staff members are doing research in various areas of environmental chemistry. He has had over twenty articles published in nationally recognized chemistry magazines/journals.

Expert #4 is a female, age 49, who holds a Ph.D. in Chemistry from the University of Illinois. She holds a management position in the Environmental Analysis Research Department of AT&T Bell Labs. One of her major duties is to ensure that the AT&T chemical processes comply with all environmental laws and regulations.

The survey given to the panel of experts was created based upon information found in three books. These texts are *The Practice of Social Research* (1995) by Earl Babbie, *The Delphi Method: Techniques and Applications* (1975) by Harold A. Linstone, Turoff Murray, and Olaf Helmer, and *A Practical Guide to Knowledge Acquisition*, (1991) by A. Carlise Scott, et al. All three provided a comprehensive background for understanding how to conduct interviews and build surveys. These books suggested using the open ended survey to allow the experts enough freedom to express their opinion. Also, the types of questions asked were chosen to determine the experts' feelings about both the overall concept of an interdisciplinary case study approach as well as the specific areas which were going to be included in the survey. Since these experts

where only being used to give guidance to the development of the case study, more rigorous methods of interviewing--i.e., the Delphi Method-- were not pursued. In later phases of assessment, more comprehensive surveys were developed to test the computer tool. At this time however, it was felt that this survey could give some insight into the progress of the project.

Once the writing of the case study had begun, the first survey was administered by the independent consultant to the panel of experts. The survey questionnaire, Figure 1, is included below.

<b>Questionnaire</b>
1) Can case studies be used to teach chemistry to first and second year students?
2) Can an interdisciplinary approach be used to examine a specific problem?
3) Are the historical aspects important to the understanding of the issues involved?
4) Are the economic aspects of the case study important to the understanding of the issues involved?
5) Are the political aspects of the case study important to the understanding of the issues involved?
6) Are the concerns of the affected industries important to the understanding of the issues involved?
7) Are the body of laws and regulations important to the understanding of the issues involved?
8) Should the chemical principles involved be presented first?
9) Should the history of the problem be presented first?
10) Should the economics behind the problem be presented first?
11) Should the politics behind the problem be presented first?

**Figure 1** Questionnaire #1

Each member of the panel of experts worked separately to respond to the questions. Unfortunately, due to the fact that a consultant no longer involved with the study administered the surveys, the author did not have direct access to the results. The consultant prepared a report detailing the results. This report, however, did not contain specific quotas from the panel of experts but instead only general trends.

According to the consultant, the panel felt the case study approach was an appropriate way to teach and should incorporate an interdisciplinary approach. The panel felt that using the chemistry curriculum as a backbone onto which the aspects of history, economics, and politics would be added was a valid choice. Significantly, the panel felt that the most emphasis should be given to chemistry and history. Economics was seen as the third most important area to be covered. Politics was seen as tied to economics and the other areas but not of the greatest importance. These results confirmed what the initial research into the case study had shown. The experts agreed that the interdisciplinary material should be infused to the chemistry curriculum. Also, the panel agreed that environmental problems require interdisciplinary solutions which are balanced and comprehensive. Finally, the panel felt that the historical aspects of the case study would be a vital tie which could bring the various parts of the case study together. Unfortunately, I could not solicit more detailed and specific information from the experts which would have allowed me to better correlate the opinions of the expert panel with the related literature because of my limited access to the expert panel.

With the case study written, it was necessary to make it more accessible to students. This would be accomplished by computerizing it.

## CHAPTER 2

### COMPUTERIZING THE CASE STUDY

#### 2.1 Computerizing the Written Case Study

With the case study written, it was necessary to transform it into a computer tool which could be used by students, teachers, and other industry experts around the world. The means of presentation chosen would have to be versatile enough to interface with many different computer systems and sophisticated enough to present the case-study in a coherent way while still being simple enough to be used effectively. It was decided that the chosen medium should be accessible via a stand-alone computer, as part of a networked system, or loaded onto a server allowing it to serve as a World Wide Web (WWW) site which can be contacted using the internet. In this way, the maximum number of users could be reached.

It was decided that the text of the case study should be transformed into a computer tool using Hypertext Markup Language (HTML). HTML inserts tags into a plain-text document such as one found in Microsoft Word. These tags allow a browser to display the marked text in a specific way. For example, if a page author wishes to underline a word, that word is placed between the appropriate tags. There are a wide range of tags which can be used to make formatting changes or even accomplish things such as blinking or scrolling text. HTML also allows for graphics in the form of compressed graphics files to be displayed. Any file in the CompuServe Bitmap Graphical Interface Format (GIF) or Joint Photographic Expert Graphics (JPEG) format can be referenced and thus displayed. The third and most significant feature of HTML is

its ability to link HTML documents together through clickable links. An author can designate a field which when clicked by a user accesses a different HTML page. These hypertext links are what allow the tool to become dynamic. All of these features made HTML good for the creation of the tool.

HTML allows for integration of text and graphics called for by the written case study as well as ease of movement needed by the users of the case study. Also, since WWW access is always increasing and the browser software is made available to schools free-of-charge, HTML became the best choice.

Once HTML was chosen, an editor for a personal computer was used to insert tags into the text of the case study. A historical overview in the form of a timeline was used as the main driver to the access of the case-study. By clicking on any underlined date, the user would be brought to the relevant part of the case study text. To make the overall learning process easier and more time conscious, the text was broken into seventeen pages. Each page has links to the next and previous page, the Goto page, and the timeline. In this way, users can move freely through and among the many pages of the tool. All seventeen pages are linked together and made accessible through three different means-- the timeline, the adjacent pages, and the Goto page. In this way, the users are able to move freely and quickly from one level to another in the case-study.

To aid the users, a main menu and a Goto page has been included. The main menu allows for general access to the case study. This page provides links to different areas of the case study such as chemistry or atmospheric chemistry. Links to the overview and the Goto page are also found on this page. In this way, users can jump

directly to pertinent information which is desired. In all cases, the text of the case-study is then accessible.

The Goto page allows users to jump to anywhere in the case study. It is accessible from all pages and leads to all pages. The Goto page is the master link allowing for ease and comfort of use.

Outside the actual case study is the case study selection page. This page is included to allow the stratospheric ozone layer depletion case study to be incorporated into a larger tool which can be used for a wider range and larger number of classes.

A tutorial which may be needed by the users who are unfamiliar with WWW browsers and the internet is also planned. This tutorial is part of the larger teaching tool and will not be discussed here. The only reference to this is in the header of the ozone case study main menu. If the on-line tutorial is not available, a written worksheet can be provided to the users who have difficulty.

## **2.2 The Computer Tool Printed Out**

The next series of pages contains the entire case-study material printed out as it appears when viewed with Netscape. The actual on-line version is intended to be in color. As a result, some of the graphics and the actual links to other pages of the case study may be difficult to see. Unfortunately, this is unavoidable.

## Case Studies

Please choose one of the four case-studies listed below.

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Click above to access the Stratospheric Ozone Depletion Case Study

---



Click above to access the Garment Waterproofing Case Study

---



Click above to access the Printing Inks Case Study

---



Click above to access the Volatile Solvent Elimination Case Study

---

A tutorial has been provided to help the user become familiar with how to use the computer tool. To view tutorial, return to the title screen and click on the bookcase icon.

[Return To Title Screen](#)



# Stratospheric Ozone Layer Depletion Case Study

This is the introductory screen of the Stratospheric Ozone Layer Depletion case study. We suggest that you begin with the overview. However, for your convenience, links to other portions of the case study have been provided. Since the case study is interdisciplinary, it is difficult to separate any one field from the others. As a result, subject areas may overlap within the body of the case study.

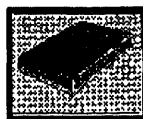
A tutorial has been provided to help the user become familiar with how to use the computer tool. To view the tutorial, return to the title screen and click on the bookcase icon.

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## Begin the Case Study

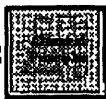
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### The Historical Overview




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Chemistry--The Beginning



OR



Atmospheric Chemistry

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Economics



OR



Politics



### The Alternatives



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Return To Case Study Selection

Return To Title Screen



## *The Historical Overview*

### **Tracing Chemistry and the Depletion of the Stratospheric Ozone Layer By Chlorofluorocarbons**

#### Begin the Case Study



*Goto anywhere in the case study*

15th Century-- Leonardo DeVinci writes that air has several constituents, one of which supports combustion.

17th Century-- Robert Boyle provides the first operational definition of an element. Also, Boyle observes that for a given number of moles of gas molecules, the pressure is inversely proportional to the volume if the temperature is held constant.

1773-1774-- Joseph Priestly discovers oxygen gas as part of his work as one of the founders of the science of chemistry, but calls it flogiston and does not recognize it as oxygen.

1775-1776-- Antoine-Laurent Lavoisier first recognizes oxygen as an element.

1800-- Jacques Charles observes that, for a given number of moles of gas, the volume is directly proportional to the absolute temperature if the pressure is held constant.

1811-- Amedeo Avagadro proposed that equal volumes of a gas at constant pressure and temperature have an equal number of molecules.

Spring 1851-- Dr. John Gorrie invents the first working refrigerator.

1871-- Mendeleev's periodic table is published in English. Many empty spaces appear where soon-to-be discovered elements will be placed.

June, 1918--General Motors begins manufacturing refrigerators for public consumption.

December 31, 1928-- The first patent is given for the formula for chlorofluorocarbons (CFC).

April 1930-- Midgley makes a presentation demonstrating the safety of CFCs.

August 27, 1930-- General Motors and DuPont form enter into a joint venture to produce and market CFCs.

1932-- The Carrier Corporation markets the first self-contained household air-conditioning unit, "the Atmospheric Cabinet."

**September 8, 1941**--Thomas Midgley Jr. receives the American Chemical Society's Priestly award for outstanding creativity in the field of chemistry.

**1956**-- America's first air-conditioned mall opens in Edina, Minnesota.

**1958**-- 90% of the theaters, 40% of restaurants, and 25% of the hotel rooms in America are air-conditioned.

**1962-1966**-- 75% of all new apartment buildings are equipped with air-conditioning.

**1963**-- 15% of the 6.5 cars in America have air-conditioning.

**1971**-- 58% of all American cars have air-conditioning, as do many truck cabs and other conveyances.

**1972**-- More than half of all residences have some form of air-conditioning.

**December 1973**-- Rowland and Molina theorize that CFCs can destroy the ozone in the stratosphere.

**June 1974**--Rowland and Molina's paper on their discovery is published in *Nature*.

**September 1974**--Rowland and Molina discuss their theory publicly for the first time at the American Chemical Society meeting in Atlantic City.

**October 1974**--A government committee recommends that the National Academy of Sciences conducts a study on the validity of the CFC-ozone theory.

**December 1974**--The first government hearings are held on the CFC-ozone theory in the United States.

**May 1975**--The CFC-ozone theory is hotly debated at the American Chemical Society meeting in Philadelphia.

**June 1975**--The Natural Resources Defense Council sues the Consumer Product Safety Commission for a ban on CFCs used in aerosol spray cans.

**June 1975**--Johnson Wax, the nation's fifth largest manufacturer of aerosol sprays, announces it will stop using CFCs in its products.

**June 1975**--A government task force called IMOS defers the decision to regulate CFCs to the pending NAS report.

**June 1975**--Oregon becomes the first state to ban CFCs in aerosol sprays.

**July 1975**--The Consumer Product Safety Commission rejects the NRDC's lawsuit claiming that there is insufficient evidence that CFCs harm the ozone layer.

**September 1976**--The National Academy of Sciences releases its report verifying the Rowland-Molina hypothesis, but says government action on CFC regulations should be postponed.

**October 1976**--The Food and Drug Administration and Environmental Protection Agency propose a phase-out of CFCs used in aerosols.

**March 1977**--The United Nations Environmental Program holds the first international meeting to discuss ozone depletion.

May 1977--Several government agencies announce joint plans to limit the uses of CFCs in aerosols.

October 1978--CFCs used in aerosols are banned in the United States.

November 1979--A second NAS report on the CFC-ozone theory is released, putting depletion estimates at 16.5 percent and saying a "wait-and-see" approach to regulations is not practical.

April 1980--The EPA announces the United States' intention to freeze all CFC production at 1979 levels.

October 1980--The EPA, under the Carter administration, releases an Advanced Notice of Proposed Rule-making outlining plans for additional CFC regulations.

July 1981--Hearings are held in Washington to discuss protection of small businesses from possible new CFC regulations. Hearings are highly critical of the Advanced Notice of Proposed Rule making.

August 1981--NASA scientist Donald Heath announces that satellite records show global ozone levels have declined 1 percent.

March 1982--The NAS releases a third report on CFC-ozone and predicts eventual ozone depletion of 5 to 9 percent.

February 1984--A fourth NAS report downplays the potential harm to the ozone layer from CFCs by lowering depletion estimates to 2 to 4 percent.

October 1984--A British research group led by Joe Farman detects a 40 percent ozone loss over Antarctica during austral spring.

March 1985--The Vienna Convention, calling for additional research and exchange of information on ozone depletion, is signed by international negotiators. Negotiators fail to agree on worldwide CFC regulations.

May 1985--Farman's paper is published in *Nature*.

August 1985--NASA's Heath shows satellite photos confirming the existence of an ozone hole over Antarctica.

January 1986--EPA releases its Stratospheric Ozone Protection Plan which calls for new studies to determine whether additional CFC regulations are needed.

June 1986--Papers are published by two research groups indicating chemicals and polar stratospheric clouds are responsible for ozone losses over Antarctica.

June 1986--CFC manufacturers suggest that safe substitutes for the chemicals might be possible for a high enough price.

September 1986--A major CFC industry lobbying group announces it will support limits on CFC growth.

September 1986--The DuPont Corporation announces it will call for limits on world-wide CFC production.

December 1986--International negotiations on ozone protection resume in Geneva after a 17 month layoff. The United States proposes worldwide CFC reduction of 95 percent by the next decade.

April 1987--Under pressure from some high-level officials, the United States backs off its original position and proposes long-term CFC reductions of 50 percent.

June 1987--NASA's Heath reports satellite findings of a 4 percent ozone loss detected over a seven year period. A NASA-sponsored study called the Ozone Trends Panel is organized to review the findings.

August 1987--The McDonald Corporation announces it will no longer purchase materials which were made using CFCs to package its food products.

September 1987--The Montreal Protocol is signed, calling for eventual worldwide CFC reductions of 50 percent.

October 1987--The Antarctic ozone expedition ends with chlorine chemicals found to be the primary cause of ozone depletion.

November 1987--A scientific conference confirms the findings of the Antarctic expedition.

November 1987--U.S. lawmakers call for new negotiations to strengthen the Montreal Protocol.

February 1988--Three U.S. senators ask DuPont to stop making CFCs.

March 1988--The chairman of Du Pont denies the request to stop making CFCs.

March 1988--The U.S. ratifies the Montreal Protocol in a unanimous vote.

March 1988--The Ozone Trends Panel announces it has found ozone losses of 1.7 to 3 percent over the Northern Hemisphere.

March 1988--Three weeks after refusing to stop making CFCs, the Du Pont Corporation announces it will cease manufacture of the chemicals as substitutes become available.

April 1988--Manufacturers of plastic foam food containers announce they will stop using CFCs.

June 1988--A leading scientist says the greenhouse effect is impacting the earth and blames the use of manmade pollutants for the global warming.

August 1988--The EPA orders domestic CFC reductions that mirror the terms of the Montreal Protocol.

September 1988--The EPA says new evidence shows that it underestimated the degree of ozone depletion and says 85 percent cutbacks on CFCs are needed.

October 1988--Scientists meeting in the Netherlands confirm the Ozone Trends Panel findings of ozone losses in the Northern Hemisphere.

January 1, 1989-- The Montreal Protocol goes into effect.

March 1989--European countries and the United States agree to faster CFC reductions but developing countries oppose the new timetable citing the costs of substitutes and scientific uncertainty.

1990-- The United States Congress passes the amendments to the Clean Air act. These amendments include Title VI, regulations concerning the protection of stratospheric ozone

1990-- The London amendments to the Montreal Protocol are ratified.

1992-- Worldwide ozone levels in the stratosphere drop to lowest levels in recorded history.

1992--Copenhagen amendments to the Montreal Protocol are ratified.

1990-1993-- DuPont's research and development arm produces substitutes for CFCs. These include partially hydrogenated chlorofluorocarbons(HCFC) and totally hydrogenated fluorocarbons (HFC)

1995-- Auto-makers begin installing air-conditioning units in cars which use HCFC-134a, a substitute for CFC-12.

June 10, 1995-- Wal-Mart opens an experimental " environmental prototype store" designed with the latest advances in environmentally conscious building materials and techniques.

August 1995--The largest hole in the ozone over Antarctica begins to form. This is the earliest a hole has formed since recordings have been made. When its growth was complete, the hole encompassed the entire continent of Antarctica and was the largest hole ever recorded.

September 14, 1995-- The CEO of Whirlpool corporation announces that the company is committed to building a large state-of-the-art plant in India to manufacture CFC-free refrigeration units.

October 6, 1995-- The Environmental Council agrees to argue for tighter rules on the use and production of ozone-destroying substances at the international conference in Vienna in November.

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# Stratospheric Ozone Layer Depletion



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## Introduction

The atmosphere in which we live is vital to all life on earth. It acts as both a source of raw materials and a means of waste disposal for almost every form of life on the planet's surface. The constant interchange between the atmosphere, soil, water bodies, and the living organisms on Earth keep the planet's ecosphere in balance. This balanced regulated state is maintained through a series of cycles which move resources from one living organism to another by use of solar energy and materials found in the land, sea, and air. Without these cycles, the system would lose its ability to maintain the homeostasis and the entire ecosystem would soon run down. By introducing synthetic chemicals into our environment, humans have unintentionally upset nature's balance. If we are not careful, the system may be pushed too far and so not be able to recover. If this happens, the delicate balance which the Earth has been able to maintain would be lost, perhaps making life no longer possible.

In the fifteenth century, Leonardo DeVinci realized that the air he breathed was comprised of more than one gas. He also noted that one of these gasses must be responsible for combustion. At that time, the science of chemistry was in its infancy. Scientists today know that the gas DeVinci was speaking of was oxygen.

## Boyle's Law

Two hundred years later, many scientists were working to explain nature. Though chemistry had not yet become a full-fledged science, at this time, many new discoveries were being made. Many different problems confronted the scientists. All worked to delineate the constituents of the world around them while quantifying these constituents' interactions.

An important early discovery was made by Robert Boyle. It concerned how gasses

act when placed under stress while holding certain variables constant. While designing vacuum pumps to remove air from vessels, he noticed something that seems quite intuitive and obvious today. If you have squeezed a sealed bag of air or a balloon, you may have noticed that it seems to push back the more you compress it. Boyle labeled this resistance, "the spring of the air" and found that he could measure it. After many experiments, Boyle saw a correlation between several of the variables. He operationalized these correlations into the law which bears his name. Boyle's law states that, for a given number of moles of gas molecules, the pressure is inversely proportional to the volume if the temperature is held constant.

Boyle's law can be expressed in a formula as follows:

If P = pressure

V = Volume

T = Temperature

n = Number of moles of gas k = constant of proportionality

Then  $V = k / P$  ( for a constant T and n)

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### *Atomic Structure*

In 1773 Joseph Priestly isolated oxygen gas. He did not identify it as oxygen but rather named it Phlogiston. A few years later, Antoine-Laurent Lavoisier recognized oxygen as an element and disproved the Phlogiston theory. He was the first person to give a practical definition of an element. An element is a substance which cannot be broken down into simpler substances by chemical processes. Even if elements are physically separated, there will come a point at which there is only one unit representing that element. This unit is known as an atom. Atoms are the smallest unit of an element that can exist as a stable entity. Even though atoms can be broken down further, any separation past this level causes the constituent parts to lose any recognition as different elements. This idea of a basic unit of matter was important to future understanding and use of the elements. Even though many elements were identified, exactly what they were and how they interacted was not understood until the atom model became known.

An atom is comprised of two major part, the nucleus at the center, and the electron cloud orbiting about the nucleus. Two types of particles contribute to the nucleus, protons and neutrons. Protons and neutrons are almost exactly the same size and mass but protons carry a positive charge with them. Compared to these particles, the electrons that whiz around the outside of the atom have almost no mass at all. Despite this relative lack of mass, about 0.0005 times that of a proton, electrons do have a negative charge that is equal to the positive charge of the proton.

In an atom that does not have a charge, the number of protons equals the number of electrons. In this way, the charges balance. If the number of electrons does not equal the number of protons, the atom is said to be an ion. Ions can be positively or negatively charged depending on whether there are more electrons or more protons.

This number of protons or electrons in a neutral atom is called the atomic number. Atomic numbers are important because each element has a unique number. Though the number of neutrons in a nucleus can vary, each additional proton signifies a new element. Different from the atomic number is the atomic mass. The mass of an atom is calculated by adding the number of protons and neutrons together to come to a total. This mass can be different for different atoms of the same element depending on the number of neutrons in the nucleus. This is why the atomic mass of an atom can vary, while the atomic number remains constant. Atoms of the same element which have different atomic masses are called isotopes. These concepts of atomic number and mass will become very important later on in this discussion.

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### *Charles' Law*

Shifting away from a quest to understand elements back to a broader look at how things interact, brings us to the investigation of another gas law. In 1800 Jacques Charles observed that, for a given number of moles of gas, the volume is directly proportional to the absolute temperature if the pressure is held constant.

Charles' law can be expressed in a formula as follows:

If  $P$  = pressure

$V$  = Volume

$T$  = Temperature

$n$  = Number of moles of gas

$k$  = constant of proportionality

Then  $V = k T$  (for a constant  $P$  and  $n$ )

### *Avagadro Law*

In 1811, Amedeo Avagadro provided the vital third part to the view of gasses and their interactions. He proposed that equal volumes of a gas at constant pressure and temperature have an equal number of molecules.

Avagadro's law can be expressed in a formula as follows:

If  $P$  = pressure

$V$  = Volume

$T$  = Temperature

$n$  = Number of moles of gas

$k$  = constant of proportionality

Then  $V = kn$  (for a constant  $P$  and  $T$ )

### *The Ideal Gas Law*

At first this may seem like a simple and almost insignificant addition to the body of knowledge. This simple formula, however, allows for the combination of Boyle's and Charles' laws into the ideal gas law.

Start by looking at the three gas laws,

Avagadro's law  $V = k_1 * n$  (for a constant  $P$  and  $T$ )

Charles' law  $V = k_2 * T$  (for a constant  $P$  and  $T$ )

Boyle's law  $V = k_3 / P$  ( for a constant T and n)

Since the volume V is proportional to the right side of each equation, using algebra to combine and rearrange the equations yields:

$$V = (k_1 k_2 k_3 n T) / P$$

After rearranging and letting the combined proportionality constant  $R = k_1 k_2 k_3$ , the equation becomes:

$$PV = n R T$$

This equation is known as the ideal gas law. Though this law can be only used to predict the action of ideal gases, it allows for a better understanding of gasses in general. Most gasses deviate from the results that the equation would predict, but the deviation is so slight that it can be neglected in all but the most critical of calculations.

Using the ideal gas law, many relationships and proportions can be derived. For example, the final volume of a gas held at constant temperature, while the pressure is changed can be determined knowing only the initial pressure, and volume as well as the final pressure.

This equation is:

$$P_1 V_1 = P_2 V_2 \text{ (T and n are constant)}$$

Many other variations of the equation can also be derived. For example, Joseph Gay-Lussac derived and tested a variation of the ideal gas law that correlated pressure and temperature when the volume and number of moles of gas were held constant. He found that as pressure decreased so did temperature. Other experimental verifications of the ideal gas law proved that it worked well for most gasses.

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### *The First Refrigerator*

In the spring of 1851 Dr. John Gorrie put Gay-Lussac's variation of the ideal gas law into practice when he invented the first working refrigeration unit. Gorrie was a physician in Florida trying to combat malaria. At that time, spoiled food was suspected as a cause of the disease. Having a good knowledge of science, money to spend, and time to devote to his interest in inventing, Gorrie set to work on his idea of a 'cool box'. The would-be inventor looked at the variation of the ideal gas law that Gay-Lussac derived. In terms of practical applications, this formula says that if a gas is allowed to expand, it will consume heat from the surroundings. Gorrie reasoned that if the surroundings were isolated, the cooling effect could be utilized to produce ice, which could be used to keep food from spoiling. Using a steam pump, Gorrie assembled the first refrigeration unit.

Unfortunately, his idea was good but his design poor. His refrigerator did not have much success, but the idea of keeping things cool by utilizing the cooling power of an expanding gas would not be easily lost. Gorrie died without seeing his idea put into productive use, but he had started something which, with a little help from scientists and industrialists, would become an integral part of American life.

### *The Early Periodic Table*

Though there had been many important discoveries in chemistry over the last few hundred years, many of the facts that were proven were not linked together in any coherent way that could help move the science forward. Many elements had been identified and many chemical theories existed to explain how and why the universe acted the way it did. In 1871, Dmitri Mendeleev published a table which would help to revolutionize how chemistry was to be carried out. Mendeleev's table listed the known elements in order of ascending atomic numbers. This was not a particularly innovative idea by itself. The twist which made Mendeleev's periodic table different was that he classified the known elements into columns and rows according to their properties as well. He left many empty spaces which predicted soon-to-be discovered elements. This table helped to guide the search for new elements and directed research into a deeper understanding of the known elements and their interactions.

More than just helping to show where new elements might be found, the periodic table showed how each element should react and identified the families of elements as they are understood today. The arrangement of the elements on the periodic table is understood to be related to the number and arrangement of electrons in each element. Today, the periodic table is complete, in the sense that there are no longer any missing elements among the first 110 atomic numbers. Chemists continue to look for and create the higher atomic number elements guided by the knowledge of how many protons the new elements should contain and how these new elements will react once they are created.

## The Periodic Table

Periodic Table of the Elements

The image shows a periodic table of elements with a map of the United States overlaid on it. The map highlights the geographical locations of various elements, such as Hydrogen (H) in the northeast, Helium (He) in the northwest, and other elements scattered across the country. The periodic table includes elements from Hydrogen (H) to Oganesson (Og), with the lanthanide and actinide series shown below the main table.

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### *Electronic Configuration*

Before discussing any more about the placement of elements on the periodic table, it is important to understand how the electrons circling the nucleus of the atoms are configured. Through experiments, scientists have demonstrated that the electrons are arranged into levels consisting of different shells. The electrons in the innermost shell are held most tightly by the atom. The further from the nucleus, the weaker the attraction the electron feels. It is said that an electron further from the nucleus is at a higher energy level, and subsequently, has more energy.

One important fact about energy levels is that they cannot hold an infinite number of electrons. Each level and shell has a specific maximum capacity. Also, both are most stable when full. The first level can hold up to two electrons. The second level has a capacity of eight. The number increases with each level but even so, atoms strive to have eight electrons in their outermost shell.

Something else to remember is that only the electrons in the outermost level or shell interact in chemical reactions. If the outer shell is full, there is very little chance that the atom will react with another atom. On the other hand, if an atom has only seven electrons it will try to find an additional electron or if the outer shell has only one electron, the atom will try to release that extra electron to move to the full shell one level lower. Knowing these facts will aid in the understanding of the periodic table.

### *The Modern Periodic Table*

In a modern periodic table, the periods of the table increase unevenly as the atomic number of the elements increase. This is a result of the way in which electrons are added to the atoms. The first energy shell in each level is known as the S. It is capable of handling only two electrons. The second shell is the P and can handle six more for a total of eight in the second period. The third level has an additional set of atomic orbitals called the D shells which can hold ten more electrons. This pattern continues toward infinity. Each new level adds twice the next odd number of electrons. If each level filled uniformly, this system would be easy to follow. Unfortunately, by looking at the chart it is easy to see that this is not happening. Looking at the table shows that the progression is 2, 8, 8, 18, 18, 32, 32, and so on. This problem might seem hard to comprehend at first, but in the end, it has a very simple explanation.

### *Filling The Electron Shells*

Atoms try to find an electronic configuration which allows them to reach the lowest energy state. This helps explain the odd progression in the periodic table as well as the reasons for the formation of molecules. As it turns out, certain electron configurations allow a lower energy state than others. The following chart shows how the different electron levels are filled to allow for this lowest energy state.

1s(2)
2s(2) P(6)
3s(2) P(6) D(10)
4s(2) P(6) D(10) F(12)
5s(2) P(6) D(10) F(12)
6s(2) P(6) D(10) F(12)
7s(2) P(6) D(10) F(12)

By starting at the top of each column and reading diagonally to the left, it is possible to see how different levels fill in orders. The number in parenthesis corresponds to the maximum number of electrons which can be placed in any one l

As can be seen from the pattern of filling, it is more advantageous for an atom to fill the 4S shell before it fills the 3P s deviation from the pattern allows for the odd, ever expanding, shape of the periodic table.

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### *Families of Elements*

To help understand the overall arrangement of the table, it is helpful to divide it into two groups; metals and nonmetals. Metals are usually typified by shiny, malleable, ductile substances that are eager to loose electrons. Conversely, nonmetals are brittle and try to gain electrons. The lower and further left on the table that one looks, the more the elements act like metals, while the higher and further right on the table one moves, the more the elements become nonmetals. In the center is a region of semimetallic compounds known as the metalloids. These can exhibit properties of both metals and nonmetals. Also, there are special cases on the table. Starting with period four, a group of elements appear. These are called the transition metals and all have very similar properties. This large collection of elements correspond to the filling of the D orbitals. Beginning in period six, there appears another collection of elements known as the rare earths or actinides. Their appearance here reflects the filling of the F orbitals. All of these metals have extremely similar chemical properties and are also very scarce.

Moving from these rather rare elements to ones that are encountered each day, let us look at the leftmost column of the chart. This group contains the family known as the alkali metals. This family is characterized by extremely reactive soft metals that will tend to form +1 ions. The family to their right are the alkaline earth metals. These are similar but tend to form a +2 ion.

Moving across the chart to the rightmost column, we find the family of elements known as the noble gases. This family is characterized by their lack of reactivity. Each member of the group has a full outer shell and so is not interested in acquiring or losing electrons. These gasses are satisfied. The next column to the left contains the family known as the halogens. This family is the most reactive group of elements known. The members of this family are eager to acquire one electron and become anions with a -1 charge.

Other families on the chart are also grouped together but because their chemical and physical reactions are complex, it is difficult to make general statements about them. Those elements in the family headed by oxygen usually try to form -2 ions, those under nitrogen form -3 ions, and those under carbon form the unique group which can either be +4 or -4 ions.

Carbon is of particular interest because of its ability to combine with almost every other element as well as itself to form long chains or polymers. A polymer is a large molecule composed of a repeating sequence of chemicals bonded together.

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### *Chemical Bonding*

It is important to understand something about chemical bonding before the discussion can move forward. All molecules are held together by bonds between atoms. A bond is an electron-static attraction between one atom and another. There are two major types of bonding, ionic and covalent. In an ionic bond, one atom transfers an electron to another. When this happens, the ionic bonds are formed due to a difference in charges. The electrostatic attraction of these different charges holds the two ions together. In covalent bonding, the atoms involved do not wish to relinquish their electrons. Instead, the atoms share a portion of the electromagnetic field of the orbiting electrons. The more intense the desire for the shared electron the stronger the bond. It is this knowledge of the elements, their atomic structure, and their bonding capability that helped move chemistry forward as a science. Once the theoretical groundwork was laid, chemists were able to use this knowledge to begin synthesizing compounds found in nature as well as create many that were not.

### *The Progress of Chemistry*

This understanding of chemical reactions, the periodic table, and the interactions of gasses made many new inventions possible. With the advent of large companies, the face of chemistry changed. These corporations created research teams to develop and synthesize new chemicals and machines which would help speed the process of development. It was these research and development groups who were largely responsible for the next wave of progress and inventiveness.

Though Gorrie was not able to see his invention make its way into households we all know that it did. Thanks to other scientists and engineers, his idea was improved upon and made functional and profitable. As the demand for refrigeration grew, so did the number of chemists and engineers working on the problems.

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### *The First Chlorofluorocarbons*

In June of 1918, General Motors joined the refrigerator manufacturing industry by purchasing a small Detroit company and renaming it Frigidaire. On the surface, this does not seem to be that significant an event. However, when General Motors began manufacturing, it also began working to perfect the products it was selling. Though many other companies were in the field, few had the quality researchers that General Motors possessed. Also, the money that could be invested by this automotive giant was unparalleled.

The research team for General Motors changed the aesthetics of the early refrigerators to make them more acceptable to the consumer. This change, along with several others, improved the physical appearance and functioning of the General Motors' units. More than any other problem, the main difficulty that still remained with all refrigerators was the refrigerant used to cool the box. Ammonia, a highly toxic and potentially explosive liquid/gas was the refrigerant of choice at the time. Many research groups tried in vain to find an adequate substitute which had as good a cooling potential, was less toxic, was safe, and would not cost an exorbitant amount.

One of General Motors' most celebrated and successful researchers was a man named Thomas Midgley Jr. Midgley had invented the lead additive for gasoline as well as many other chemical innovations. When he started work on the problem of the refrigerator, no one thought that his next creation would change the world so significantly, but it did. On December 31, 1928, Frigidaire received the first patent for the class of compounds which would come to be known as chlorofluorocarbons (CFC). With this patent, the modern age of refrigerators and air-conditioning began.

In retrospect, the creation of the first chlorofluorocarbons was a momentous discovery. At the time, however, no one knew exactly what these new chemicals could be used for. Slowly, CFCs made their way into the market. Before anyone would rush to purchase and use this new chemical, many tests and studies would need undertaken. In April 1930 Midgley made a presentation demonstrating the safety of CFCs at the Atlanta meeting of the American Chemical Society. Midgley began by placing an empty glass jar on a table in front of the assembled crowd. Into the jar, he poured liquid CFCs, which appeared to be white and opaque. The liquid began to boil instantly as soon as it warmed to room temperature. As the vapors billowed up out of the jar, Midgley placed his face over its mouth and took a deep breath, inhaling the cold stream. He went on to explain that CFCs are non-explosive, have not harmed any animals, and except for an intoxicating effect, have no effect on humans. Moreover, CFCs are chemically inert and, most importantly, are perfect refrigerants. The crowd was thoroughly impressed. A few months later, on August 27, 1930 General Motors and DuPont entered into a partnership to produce CFCs under the trade name Freon. Scientists at the time, performed every test on CFCs that could be imagined. In the end, they were found to be safe to humans, construction materials, and the environment. Best of all, they were inexpensive and highly useful. Not until many years later did a new group of scientists find out that CFCs could be very harmful to everything on earth.

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### *Naming Freons*

As part of the marketing plan, Du Pont developed a numbering system to refer to the chlorofluorocarbons. Each species of CFC is given a number which can be used to determine its structural formula. For example, trichlorofluoromethane (CFC13) is Freon-11. The formula for decoding this system is simple.

Add 90 to the Freon number and interpret the three digit result according to the following system: the left digit is the number of carbon atoms, the middle digit is the number of hydrogen atoms, and the right digit is the number of fluorine atoms. Conspicuous by its absence is chlorine. All the bonding sites that are not taken up by either fluorine or hydrogen are filled by chlorine. For example, to determine the formula for Freon-12:

$$\text{CFC -12} \rightarrow 12 + 90 = 102$$

This implies:

1 Carbon

0 Hydrogen

2 Fluorine

To determine the number of chlorine atoms, begin by imagining the methane building block. Then, using the numbers from the formula above, fill in the information that is derived. Finally, count the number of vacant sites. This number equals the number of chlorine atoms. In the case of CFC-12, 1 carbon has four bonding sites. Since there are 0 hydrogen and 2 fluorines, this leaves 2 bonding sites (4 carbon - 2 fluorines). Chlorines fill the empty sites meaning there are two chlorines.

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### *Characteristics of Freons*

In general, all Freons are carbon compounds containing chlorine, fluorine, and/or bromine. The most common Freon compounds are chlorofluorocarbons or CFCs in particular, CFC-12 whose chemical formula is  $CCl_2F_2$ . Freons are used so widely by industry because of their high densities, low boiling points, low viscosity, and low surface tension. In addition, they are easily liquefied making them ideal for use as refrigerants and solvents. All of these properties made Freons a best seller amongst many industries. Also, the properties made them useful in many other areas. Freons are widely used as solvents, propellants, fire extinguishers, and blowing agents.

Before looking any further into the spread of CFCs, it is important to understand why they are so chemically useful. Since CFC-12 is the most widespread, it will serve as a good example of the chemical usefulness of the entire class of chemicals, known as CFCs. From the discussion above, the molecular formula for CFC-12 is  $CF_2Cl_2$ . The name of this compound is dichlorodifluoromethane. To imagine what this would look like in three dimensional space, begin by envisioning a pyramid with a triangle as its base. Place the carbon atom in the center of the triangle with the chlorines and fluorines at the four points. This is known as a tetrahedral configuration.

Each halogen is fighting to draw one electron away from the central carbon atom. At the same time, the carbon holds the electrons in the covalent bonds so it does not lose them. Since fluorine and chlorine are aggressive elements, the bonds which are formed are very strong. The chlorine acts as a stabilizing agent giving even more stability to this molecule.

These strong covalent bonds and added chlorine stability make CFC-12 inert. This means it does not react with other molecules in its surroundings. Besides its chemical inertness, CFC-12 has many other chemical and physical properties that make it ideal for use in many industrial fields. Its boiling point allowed it to be used as a refrigerant eliminating the danger of explosion or toxicity that was associated with ammonia. Also, because it was inert and nontoxic, it could be used to blow foam for formation of containers or insulation. These same properties made it perfect in medical inhalers and aerosol spray cans. Other applications also arose as the other CFCs were produced. The low costs of production coupled with their versatility and widespread appeal helped them to find their way into many industrial operations.

The same property of inertness which makes CFCs so useful in industry would one day prove to be what makes them so dangerous to the planet. Even as CFCs became more widely spread in industry, they were slowly being vented to the atmosphere. At the time this was not seen as bad practice because they were thought to be safe. Unfortunately, CFCs do not naturally biodegrade. As a result, they persist in the atmosphere. Through natural processes, they make their way up into the stratosphere where the real problem begins. From their inception until the mid seventies, however, CFCs were seen as safe, useful, and noncontroversial.

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### *The Spread of Chlorofluorocarbons*

With the introduction of CFC-11 and CFC-12, the air-conditioning and refrigeration industries began to boom. In 1932, the Carrier Corporation manufactured and marketed the first self-contained household air-conditioning unit, "the Atmospheric Cabinet." This brought the idea of comfort through technology and chemistry to the household consumer. It was not long before consumers devoured the new comforts brought by synthetic chemicals. Though consumer acceptance was slow at first, it eventually became an irresistible force.

Just before the beginning of the second World War, on September 8, 1941, Thomas Midgley Jr. received the American Chemical Society's Priestly award for outstanding creativity in the field of chemistry. His contributions to the field were extensive. CFCs are but one of his many innovations, all of which were designed to help humans live better and longer. In less than fifty years, however, this part of his work has come to be seen as something which could endanger the lives of all humans and perhaps, the planet Earth.

After the war, consumers demanded the many things that they had to do without during the times of rationing and conserving. Consumption was high, as were most people's hopes for the future. In 1956, America's first air-conditioned mall opened in E. Minnesota, ushering in the age of convenience and shopping pleasure. By 1958, 90% of the theaters, 40% of restaurants, and 25% of the hotel rooms in America were air-conditioned.

This idea of air-conditioned comfort was not confined to areas of entertainment. Between 1962 and 1966, 75% of all new apartments built were equipped with air-conditioning. Once the living environment had air-conditioning, American automobiles with air-conditioning soon followed. In 1963, 15% of the 6.5 cars in America had air-conditioning and only eight years later, in 1971, 58% of all American cars had air-conditioning, as did many truck cabs and other conveyances. By 1972, the living areas of America were being air-conditioned as well. More than half of all residences were equipped with some form of air-conditioning.

The spread of CFCs had not only made its way through American industry and the world, but these products had followed people everywhere. It had become possible for a person to remain within a few feet of air-conditioned space from the time they left home in the morning until they returned at night. This one invention had become so commonplace that many could not imagine doing without it even for a short time. As with many other CFC related technologies, the usefulness and reliability of the technology made it very popular. CFCs did their job cheaply, efficiently, and well. For over forty years, no one thought there would ever be a problem with these wonder chemicals that had become a vital part of so many people's daily lives.

In December of 1973, two scientists made a discovery that would change the way the scientific community and the general public would view CFCs. F. Sherwood Rowland and Mario Molina had studied the effects of chlorofluorocarbons in the upper atmosphere and had concluded that these substances had the potential to deplete the ozone in the stratosphere. The significance of what they were claiming was so profound that they knew there would be a great deal of discussion about their theory. In order to understand what the Rowland and Molina theory suggested, it is necessary to discuss some facts about the Earth's atmosphere and the molecules that are found there. In particular, ozone.

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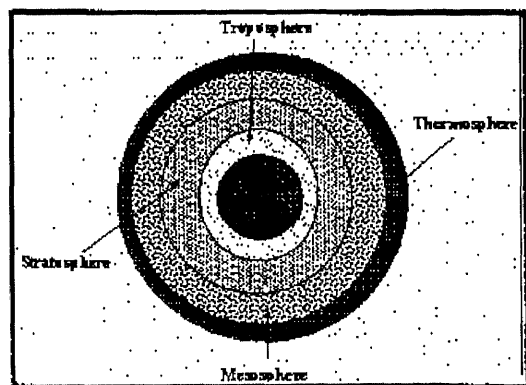
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### *The Earth's Atmosphere*

Before discussing the CFC problem, it is necessary to understand how the Earth's atmosphere is broken into layers. There are four distinct areas of air surrounding the Earth. Each has distinctive characteristics which change as the distance from the Earth's surface increases. The area humans live in is known as the troposphere. It begins at the surface of the earth and extends for 7-10 miles (11-16 km). The temperature and pressure decrease rapidly with altitude until the tropopause is reached. The tropopause is an area at which a temperature inversion occurs. This area acts as a nearly impervious barrier to most of the water trying to rise out of the atmosphere. This is important because what little water passes this point can escape into space.

Above the troposphere is the stratosphere which extends to a point approximately 31 miles (50 km) above the Earth's surface. Temperature remains fairly constant near the tropopause but begins to increase near the upper bound of the stratosphere as solar radiation increases. The water that passes the tropopause forms clouds here. The most important molecule in the stratosphere is ozone.

Next comes the mesosphere. It extends from the top of the stratosphere to an altitude of 50 miles (80 km). Finally, the top of the atmosphere is known as the thermosphere. It begins at 50 miles and continues to outer space. The temperature continues to increase through the mesosphere and the thermosphere.



Ozone is of concern to us when it is in the lower two levels of the atmosphere, the troposphere and the stratosphere. No matter where it is found, ozone is a relatively unstable molecule. An ozone molecule consists of three atoms of oxygen bound together in a triangular fashion. Although it represents only a tiny fraction of the atmosphere, ozone is crucial for life on Earth.

Depending on where ozone is located, it can either protect or harm life on Earth. In the stratosphere, ozone acts as a shield to protect Earth's surface from the sun's harmful ultraviolet radiation. Without this shield, ultraviolet levels at the Earth's surface would be higher and humans would be more susceptible to skin cancer, cataracts, and impaired immune systems. In the troposphere, however, this same ozone molecule is a harmful pollutant that causes damage to lung tissue and to plants.

The amounts of helpful and harmful ozone in the atmosphere depend on a balance between processes that create it and those that destroy it. An upset in the ozone balance can have serious consequences for life on Earth. Scientists are finding evidence that changes are occurring in ozone levels. The harmful ozone is increasing in the air we breathe, while the helpful ozone is decreasing in our protective ozone shield. In the next few pages, the processes that create and destroy the helpful ozone will be described. Also, the way that humans effect these processes will be discussed.

At the top of the stratosphere ozone is created and destroyed primarily by ultraviolet radiation. The air in the stratosphere is

bombarded continuously with radiation from the sun. The ultraviolet rays, which are part of this light, strike molecules of ordinary oxygen (O<sub>2</sub>) causing them to split into two single oxygen atoms, known as atomic oxygen or oxygen radicals. A freed oxygen atom then can collide with an oxygen molecule (O<sub>2</sub>), and form a molecule of ozone (O<sub>3</sub>).

This process absorbs much of the ultraviolet radiation which would otherwise reach the Earth's surface. Ironically, this same ultraviolet radiation also causes the destruction of ozone. When an ozone molecule (O<sub>3</sub>) absorbs even low energy ultraviolet radiation, it splits into an ordinary oxygen molecule (O<sub>2</sub>) and a free oxygen atom (O). The free oxygen atom then may bond with an oxygen molecule to make another ozone molecule, or it may steal an oxygen atom from an ozone molecule to make two ordinary oxygen molecules. Some scientists call these processes of ozone production and destruction, initiated by ultraviolet radiation, the "Chapman Reactions."

Natural forces other than the Chapman Reactions also affect the concentration of ozone in the stratosphere. Since ozone is such a highly unstable molecule, it reacts very easily, readily donating an oxygen molecule to nitrogen, hydrogen, or chlorine found in natural compounds. These elements always have existed in the stratosphere, released from sources such as soil, water vapor, and the oceans.

In addition, ozone levels can change periodically as part of regular natural cycles such as the changing seasons, sun cycles and winds. Moreover, volcanic eruptions may inject materials into the stratosphere that can destroy ozone.

Over the Earth's lifetime, natural processes have regulated the balance of ozone in the stratosphere. An easy way to think about the ozone balance is to imagine a plastic bag being filled with water. As the bag fills, a hole is punched in it to allow water to escape. As long as water escapes at the same rate that water is being poured in, the amount of water in the bag will remain the same. Likewise, as long as ozone is being created and destroyed at the same rate, the total amount of ozone will remain the same.

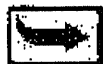
### *Human Activity and the Atmosphere*

In the past two decades, however, scientists have found evidence that human activities are disrupting the ozone balance. Human production of chlorine-containing chemicals such as chlorofluorocarbons (CFCs) has added an additional force that destroys ozone. (CFCs are compounds composed of carbon atoms bonded to chlorine, fluorine.) As was seen earlier, CFCs are stable and thus do not react easily with other chemicals in the lower atmosphere. One of the few forces that can break apart CFC molecules is ultraviolet radiation in a process called photochemical decomposition. In the lower atmosphere, however, CFCs are protected from this radiation by the ozone layer. So, CFC molecules can migrate intact into the stratosphere where they then are photodecomposed. At first, scientists thought CFCs were too heavy to make their way into the upper atmosphere. Although the CFC molecules are heavier than air, the mixing processes of the atmosphere lift them into the stratosphere. The mixing process takes many years, up to fifty, and so the problem is not easily noticed. The ozone in the stratosphere today is being destroyed by CFCs released many years ago.

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### *The Destruction of Ozone*

Once in the stratosphere, CFC molecules no longer are shielded from ultraviolet radiation by the ozone layer. Once exposed to the sun's radiation, CFC molecules release a chlorine atom or free radical. The chlorine then can react with ozone molecules, taking one oxygen atom to form chlorine monoxide and leaving an ordinary oxygen molecule behind.

If each chlorine atom released from a CFC molecule destroyed only one ozone molecule, CFCs probably would pose very little threat to the ozone layers. However, when a chlorine monoxide molecule encounters a free atom of oxygen, the oxygen atom bonds with the chlorine monoxide, forcing it to release the oxygen. The chlorine atom is then released back into the stratosphere to destroy more ozone. This reaction pathway is repeated thousands of times before it is eliminated by bonding with another molecule.

Fortunately, chlorine atoms do leave the atmosphere or there would be no ozone left. When a free chlorine atom reacts with gases such as methane (CH<sub>4</sub>), it is bound up into a molecule of hydrogen chloride (HCl), which can be carried from the stratosphere into the troposphere, where it can be washed away by rain. This removal process is important because it means that if humans stop adding compounds to the stratosphere, eventually, they will wash themselves out and everything will return to normal.

The reaction pathway by which CFC molecules are photodecomposed and work to destroy stratospheric ozone was first theorized by Rowland and Molina. After many years of presentations, papers, disputes, discussions, and debates, the theory was accepted. By that time, a great deal of evidence had been gathered to support the Rowland and Molina theory as well as show that there was indeed a hole in the ozone layer above the continent of Antarctica.

### *The Ozone Hole*

In the area over Antarctica, clouds hold ice particles that are not present at warmer latitudes. Reactions occur on the surface of the ice particles that accelerate the ozone destruction caused by stratospheric chlorine. This phenomenon has caused documented decreases in ozone concentrations over Antarctica. In fact, ozone levels drop so low in spring in the southern hemisphere that scientists have observed what they call a "hole" in the ozone layer. At first this was not that horrifying a discovery because there were no people living on the continent. Unfortunately, the conditions worsened and spread. Also, at the end of spring, the hole lost its integrity and shifted to more populated areas such as Australia and southern Chile. Scientists began to see a global dilution of ozone as more and more ozone was destroyed in the ozone hole.

In addition, scientists have observed declining concentrations of ozone over the whole globe. In the second half of 1992, for example, world-wide ozone levels were the lowest ever recorded.

Since the 1920's, ozone has been measured from the ground. Scientists place instruments at locations around the globe to measure the amount of ultraviolet radiation getting through the atmosphere at each site. From these measurements, they calculate the concentration of ozone in the atmosphere above that location. These data, although useful in learning about ozone, are not able to provide an adequate picture of global ozone concentrations.

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### *The Role of Science*

Contrary to the image created by the term "ozone layer," the amount and distribution of ozone molecules in the stratosphere vary greatly over the globe. Ozone molecules drift and swirl around the stratosphere in changing concentrations. Therefore, scientists observing ozone fluctuations over just one spot could not be confident that a change in local ozone levels meant an alteration in global ozone levels, or simply a fluctuation in the concentration over that particular spot.

In December of 1974 the first government hearings in the United States were held on the CFC-ozone theory. These hearing were the opening volley in a war over CFCs in the United States and around the globe. Many governmental and non-governmental agencies worked to find answers to the questions raised by the Rowland and Molina theory. Once enough scientists agreed to the idea that CFCs could deplete stratospheric ozone, these groups began working to ban CFCs.

Many companies saw that CFCs were dangerous and not essential to their product lines. These companies voluntarily banned CFCs. Both state and federal governments moved to give the CFC ban the force of law in the following years.

Even so, there was still debate over the extent to which CFCs actually destroyed the ozone layer. In August, 1981 NASA scientist Donald Heath announced that satellite records showed ozone over the earth had declined 1 percent. From that point on, there was little question that there was a problem and that something needed to be done about it. Unfortunately, the political process did not act swiftly enough for some and moved too quickly for others. Though the scientific facts had been debated for over ten years, there was still no clear plan of action.

Satellites had given scientists the ability to overcome the problem of uncertainty because they provide a picture of what is happening simultaneously over the entire Earth. However, the speed of ozone depletion was still debated and only slowly was the seriousness of the ozone depletion problem realized. Even the ozone hole did not seem to give enough force to the arguments for banning CFCs. Many different theories were postulated to explain the problem. In the end, CFCs were blamed and the global consensus began to build behind the idea that CFCs should be banned. Scientists had finally conceded that though there were natural forces at work which could deplete ozone, human interference in the natural cycles had accelerated the process of ozone destruction. Without some type of action, the ozone layer would continue to deteriorate until it was no longer able to protect the surface of the Earth from ultraviolet radiation.

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### *The Montreal Protocol*

If scientists can separate the human and natural causes of ozone depletion, they can formulate improved models for predicting ozone levels. The predictions of early models already have been used by policy makers to determine what can be done to reduce the ozone depletion caused by humans. For example, faced with the strong possibility that CFCs could cause serious damage to the ozone layer, policy makers from around the world signed a treaty known as the Montreal Protocol in 1987. The signatory countries agreed to reduce production of CFCs by 50% from the 1986 baseline values by 1996. In order to achieve this goal, the protocol set out different phase-out schedules for allowable and accelerated phase-outs. These two plans were at opposite ends of the spectrum. Accelerated refers to the fastest possible removal while allowable is the removal at the last possible moment.

The protocol also made some concessions to less developed countries (LDCs). These concessions included a ten year grace period before compliance was required as well as a recommendation to the more developed countries to help pay for the transition to CFC alternatives. Even though there was scientific consensus concerning the harmful nature of CFCs, the economic benefits provided by using the chemical provided a formidable problem which needed to be overcome. LDCs could not or would not forgo their use without some attractive economic incentives. This interplay between the facts that science promotes and the economics which drives society, is the balancing act that policy-makers must try to control. Though the original protocol was not perfect, it was a good attempt at trying to balance international environmental concerns about the depletion of the ozone layer and the economic concerns of many of the LDCs who would have to comply with its cuts.

The initial ratifiers of the protocol included Canada, Denmark, Egypt, Finland, France, West Germany, Ireland, Italy, Japan, Malta, Mexico, The Netherlands, New Zealand, Norway, Spain, Sweden, The United Kingdom, The United States and The USSR. The protocol went into effect on January 1, 1989 after these countries ratified it. Table 1 shows the major emitters of CFCs at that time.

TABLE 1: Major Emitters of CFCs in 1986

COUNTRY	RANK	CFC EMISSIONS (1000 METRIC TONS)	PERCENT OF WORLD TOTAL
U.S.	1	128	21.4
JAPAN	2	92	16.4
USSR	3	87	16.4
GERMANY	4	74	13.7
UK	5	48	9.2
ITALY	6	35	6.7
FRANCE	7	34	6.7
SPAIN	8	21	4.2
CHINA	9	20	4.1
CANADA	10	11	2.3
AUSTRALIA	11	8	1.6
ALGERIA	12	7	1.6
TOTAL		580	78.4
WORLD		740	100

This table shows the unbalanced contribution to the problems by members of the world community. The top twelve emitters contribute 78.4% of the world total of CFCs. Worse than that, the top three emitters—the U.S., Japan, and the USSR—contribute a combined 292,000 metric tons of the world's total of 580,000 metric tons of CFC pollution. These three nations emit 50.4% of the CFCs in the world's atmosphere. Facts such as these, coupled with continuing pressure from world governments and nongovernment organizations, allowed amendments to the original Montreal Protocol to be developed.

Though the 1987 Montreal Protocol was a good beginning, more evidence of rapidly increasing ozone depletion over both poles

led to a rising tide of concern and a movement for accelerated phase-out of CFCs. In 1990, the London Amendments were passed. The signatory countries for these new amendments agreed to a total ban of CFCs by the original 1996 date. Also, they established a relief fund for LDCs that would be adversely affected by the new agreement. The original protocol did not attract China or India—two major potential users. After the amendments, however, these and many other countries participated in the ban with the understanding that the fund of \$260 million dollars would be used to offset their costs. Two year later, the Copenhagen Amendments increased the fund to over \$500 million and accelerated the compliance schedule. These adjustments have made the Montreal Protocol an effective international agreement that has succeeded in gathering support from the nations of the world.

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*Goto anywhere in the case study*

## Stratospheric Ozone Layer Depletion



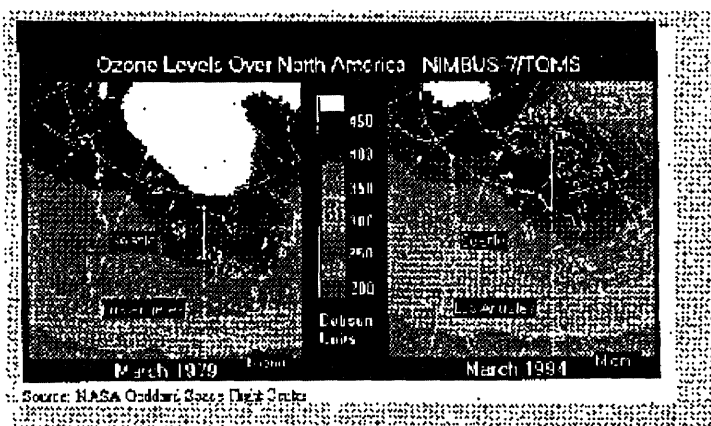
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### Monitoring Ozone From Space

However, scientists agree that much remains to be learned about the interactions that affect ozone. To create accurate models, scientists must study simultaneously all of the factors affecting ozone creation and destruction. Moreover, they must study these factors from space continuously, over many years, and over the entire globe. NASA's Earth Observing System (EOS) will allow scientists to study ozone in just this way. The EOS series of satellites will carry a sophisticated group of instruments that will measure the interactions of the atmosphere. These measurements will increase dramatically our knowledge of the chemistry and dynamics of the upper atmosphere and our understanding of how human activities are affecting Earth's protective ozone layer.

A graphic example of what satellites can reveal is shown below.



This figure shows the difference in the thickness of the ozone layer over North America between 1979 and 1994. A dramatic example such as this makes the problem very clear. In only fifteen years, the ozone layer has been degraded significantly. Luckily, something has been done about it.

In response to the Montreal Protocol and public pressure resulting from the findings of scientists, governments around the world began passing legislation which restricted or banned the use of CFCs. The United States was no different. Individual state legislatures as well as the Congress passed laws banning CFCs. These laws grew more stringent and broadened to encompass more products as time passed. By the 1990's, CFCs had been banned in the United States with only slight exceptions for medical and other highly specialized uses. Even with these types of regulations, it was important that the corporations of the world agreed to the Montreal Protocol and other regulations.

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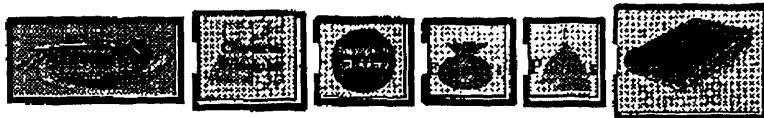
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*Goto anywhere in the case study*

## *Stratospheric Ozone Layer Depletion*



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### *Alternatives*

An important step forward in the struggle to remove CFCs from the atmosphere was fought on the economic front. Just as the economic attractiveness of CFCs made them spread so quickly through industry, consumer concerns and eventual disuse of the product helped remove them from many areas. In 1990, DuPont Chemical company, the largest producer of CFCs, agreed to a two-phase removal plan in which substitutes would be developed and then slowly phased into the existing industrial system. This corporate backing of the CFC removal program helped immeasurably. Many other companies worked to reduce the use and release of CFCs in their industrial and corporate facilities around the world. Also, many entrepreneurs have used the idea of ozone-safe products to further their business and increase profits. As consumers became aware of the problems and understood what they could do to help, business and industry has worked harder to solve the problem and find a better way of conducting their operations.

DuPont's answer to the problem of CFCs was to develop less chlorinated fluorocarbons that would impact the ozone layer less severely. They began by introducing hydrochlorofluorocarbons (HCFCs). These were CFCs with chlorine partially replaced by hydrogen molecules. As an interim measure these chemicals proved very useful. They began the phase-out of CFCs without too great a capital cost to industry and without causing too great of an inconvenience to consumers. HCFCs were not as damaging to the stratospheric ozone layer but were not completely safe. Tests showed that they could still break down and deplete the precious ozone. As a more permanent replacement, DuPont announced that it had developed a line of hydrofluorocarbons (HFCs) which contained no chlorine and thus posed a greatly reduced threat to the ozone layer.

Along with the work by DuPont, several other alternatives have been suggested. Cyclopentane and cyclohexane have been put forth as replacements for coolants. Nitrogen gas can be used as a blowing agent. Many other safe and easily obtainable alternatives exist and have been used successfully for years. CFCs in aerosol cans have been replaced with air pressure or other propellants. With a little effort, it seems that CFCs have been replaced without a tremendous furor as was expected when the idea of their replacement first came to the table for discussion.

Though the strides made by DuPont and the other scientists working to provide alternatives to CFCs are significantly reducing the quantity of CFCs being released, more can be done. Companies have seen that reducing the use of CFCs is an effective way of stopping their release without waiting for replacements. AT&T, for example has worked to prevent the release of CFCs by auditing their facilities and finding ways to cut back on their consumption of the chemicals. Other companies have found that manufacturing CFC-free products has become very lucrative. Whirlpool has recently opened a plant to manufacture CFC-free refrigerators in the India. Other companies have begun selling environmentally safe products to consumers. In 1995, Walmart opened the first entirely environmentally safe shopping area in the world. These types of innovations and forethought will be necessary to stop the depletion of the stratospheric ozone layer along with many of our other environmental problems. Cooperation between scientists, politicians, economist and many others will be vital to the continued success of the world as a whole. Global problems must have global solutions reached through global consensus and understanding.

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*Goto anywhere in the case study*

# GOTO:

## Ozone Case Study Main Menu

### Timeline

<b>PAGE</b>	<u>1</u>	<b>PAGE</b>	<u>2</u>	<b>PAGE</b>	<u>3</u>	<b>PAGE</b>	<u>4</u>	<b>PAGE</b>	<u>5</u>	<b>PAGE</b>	<u>6</u>	<b>PAGE</b>	<u>7</u>
<b>PAGE</b>	<u>8</u>	<b>PAGE</b>	<u>9</u>	<b>PAGE</b>	<u>10</u>	<b>PAGE</b>	<u>11</u>	<b>PAGE</b>	<u>12</u>	<b>PAGE</b>	<u>13</u>		
<b>PAGE</b>	<u>14</u>	<b>PAGE</b>	<u>15</u>	<b>PAGE</b>	<u>16</u>	<b>PAGE</b>	<u>17</u>						

### Title Page

## 2.3 Explaining the Goals of the Case Study

### 2.3.1 Design Features

Though it is difficult to grasp the full effectiveness of the tool without working through it on the computer, the printout does give an idea of how it will be used as well as show the content of the case study. The first page of the printout shows how the ozone case study will be integrated into the larger tool. The case study selection page lists the ozone layer depletion case study as the first of four case studies which will be used by the larger tool to teach students.

Once the user enters the ozone case study, the interdisciplinary nature of the tool is exemplified by the main menu. The hierarchy of the icons presented on the second page of the printout shows the various fields which comprise the case study. Also, the structured hierarchy and graphical reference points presented there are designed to help the user understand the layout of the case study. In this way, as the user goes through the narrative, they have an easy to follow set of icons which help them remain in control of their position within the case study.

Next comes the timeline. This page gives the history of the problem as well as provides a thread that ties the case study together. The underlined dates on this page allow the user to connect to that date in the narrative portion of the case study. The timeline contains all the dates in the case study as well as some that are not specifically included in the narrative. This is done intentionally to ensure that the users read the timeline for its information as well as use it as a tool to access the narrative. The timeline is an interdisciplinary tool even though it is representative of the historical component.

All the other aspects of the case study must be represented in the historical timeline in one way or another. There are, however, gaps in the dates related to discussion of basic chemical principles. This occurs because it is necessary to be teaching chemistry and atmospheric chemistry while moving through the case study.

The actual narrative begins with a brief piece of history and then moves into the chemistry. As can be seen on any of the pages, an icon heads each page to assist the students. The largest component of the first portion of the case study is chemistry. This is done for two reasons. First, chemistry serves as the driving curriculum for the teaching tool. As a result, there must be a large portion of this material to allow the educator to use it as part of the class. Secondly, the students need to feel that they are in a familiar surrounding before being exposed to foreign concepts. In this way the new material is worked into the students' understanding slowly and unobtrusively. The students will then be more likely to keep the knowledge with them and spend more time using the tool.

Besides the goals accomplished by the design of the tool itself, many of the aspects of the related literature have been incorporated into the narrative to help the learning process. Each of the pieces mentioned in section 1.2 of this thesis will be discussed below.

### **2.3.2 Incorporating Ideas from Fundamentals of Ecology**

As was stated earlier in this thesis, the science of ecology brought together many different aspects of other sciences to form a new hybrid science. This tool takes a similar approach to the concepts of chemistry which relate to the depletion of the stratospheric ozone layer depletion problem. Though the tool breaks the many fields into sections, the

interdisciplinary nature of the problem is maintained. The integrity of the overall case study does not suffer as one field takes precedent over others. The first eight pages of the tool are heavily weighted with the fundamentals of chemistry which are necessary to teach students the core curricula. Even so, other aspects can be seen to have influence in these pages. In the remainder of the tool, the interdisciplinarity becomes more pronounced. The sections devoted to economics, politics or chemistry all become intertwined as the case study moves towards the final pages. In the end, a fully interdisciplinary look at the problem is achieved.

More than just providing an understanding of how humans interact with their environment and solve problems, the tool gives students a sense of how the various fields come together to help identify and solve the problems. Also, the tool shows how experts from these various fields must all work together to solve the global problems presented by environmental issues such as the depletion of the stratospheric ozone layer and global warming.

### **2.3.3 Incorporating Ideas from Aldo Leopold's Land Ethic**

The message put forth by Aldo Leopold was one of diversity and expanded thinking. Hopefully, this message has been incorporated throughout the tool. In every area, the idea that cooperation between disciplines is a vital part of all scientific and social interactions is put forth. As it is created to be interdisciplinary, the tool tries to blend the many specializations into a combined and more effective whole. This idea is born out in the last four pages of the tool when it begins discussing the Montreal protocol and the many ways that humans worked to solve the problem they had created. Bringing together



many disparate groups of people to work on the problem and finally agree upon a solution is a shining example of what Leopold had thought of as the Land Ethic and the diverse approach to problems of the environment.

A larger focus on the land ethic is the motivation behind the final alternatives page. This discussion shows that humans have broadened their idea of ethics beyond other humans, beyond the land, and beyond any one portion of the globe. The new view of the global problem which the depletion of the stratospheric ozone layer presents has led to a new global ethic of the biosphere. Though it has not been expanded to all problems and all peoples, the removal of CFCs from the world is a first step. Moreover, this tool shows that not only is this type of ethic possible, but it has been accomplished on a global scale in the Montreal Protocol.

#### **2.3.4 Incorporating Ideas from Small Is Beautiful**

Besides stressing the importance of education and resolution of problems by groups, Schumacher's work pointed out how many environmental problems would need to be solved. The material concerning the debate over the Rowland and Molina theory relates back to this idea of divergent problems. Once humans learned that the problem existed, they worked diligently to make the necessary changes. However, first scientists needed to agree that a future problem which had not yet manifested itself could exist. Even though evidence was not yet available, the theoretical arguments of Rowland and Molina were strong enough to convince the scientific community. Once the divergent problem was resolved and a consensus reached, a solution to the problem could be found.

The material on page fifteen concerning the Montreal Protocol is a perfect example of this idea put into practice. By international cooperation a compromise solution to a divergent problem was reached by a diverse group of individuals. On the following two pages, the role of science in helping solve the problem was explained in the context of human interaction and compromise. In the end, Schumacher's ideas about education and human interaction were represented in the body and spirit of the tool.

### **2.3.5 Incorporating Ideas from The Limits to Growth**

The idea that human focus must be expanded into the future and past the borders of a person's house, town, or country is evident in the tool during the discussion of the Montreal Protocol. Though the stratospheric ozone layer depletion problem had the potential to affect everyone, and was truly a global dilemma, the response did not have to be a global response. Since CFCs take so long to reach the stratosphere where they can cause a problem and the effects are not directly felt by those who released the CFCs, the Montreal Protocol might never have come about. The tool incorporates the global response to a future problem to show that this is vital to the environmental problem solving process. The idea that many of the nations of the world could look beyond their borders and their interests in the immediate future, is a vital part of environmental problem solving. The world's response to the ozone depletion problem showed that cooperation was possible and an important part of the problem solving process.

When there is a fire at a hazardous waste site or an explosion near a person's house, the danger is immediate and personal. Unfortunately, the problems of stratospheric ozone layer depletion is much less immediate and personal and so is often

forgotten or dismissed. The tool brings the importance of the problem to the forefront and shows how action now is necessary to avoid a catastrophe.

### **2.3.6 Incorporating Ideas from Earth In The Balance**

The ideas of this text were represented in three ways. First, by presenting information in an interdisciplinary manner, the tool helps provide the student with information while giving them a context to place it within. Secondly, by showing how the problem of stratospheric ozone layer depletion is global, the tool touches on many of the same themes put forth by Vice-President Gore. Finally, by showing that through global responses to problems such as these, the tool demonstrates that cooperation amongst nations is possible. These three ideas are an integral part of the tool and vital to its success.

### **2.3.7 Incorporating Ideas from Environmental Education Curriculum Planning**

The ideas from the planning guide are woven throughout the entire case study. The tool begins with a large chemistry component. This is the curriculum that serves as the backbone of the tool. Then, the interdisciplinary environmental ideas are slowly added to the tool. This is the infusion portion of the case study. By presenting the principles of chemistry in the first eight pages of the tool, the existing chemistry curriculum was firmly established. Slowly, over the next nine pages, the environmental ideas are infused and intertwined with other chemical principles necessary to the understanding of the subject matter being discussed. By the end, all the fields have come together into a truly

interdisciplinary discussion that students can understand and with which they can feel comfortable.

### **2.3.8 Incorporating Ideas from Chemistry In Context.**

Though the text that was developed was broader than that contained in the *Chemistry In Context* (1994) text, many of the ideas were included. The entire section on atmospheric chemistry was reflected in the tool. The material was not approached in the same way or even described similarly, but the inclusion of information that tied the abstract facts back to the real-world that the students knew was included. Throughout the tool, references, examples, and easy to understand descriptions were used to help place chemistry in context. Also, the text helped to insure that the language of the stratospheric ozone layer depletion case study remained simple enough for the students to follow with ease.

Most importantly, the *Chemistry In Context* text gave a good example of how an interdisciplinary text should be constructed. Similarities in style can be seen between *Chemistry In Context* material and the tool. Even though the tool has more and broader information, it remains true to the intent of the *Chemistry In Context* material as well as all the ideals set forth by the related literature.

### **2.3.9 The Overall Usefulness of the Tool**

There are some overall design decisions which were made to help the tool be more effective and useful. Though illustrations are easily incorporated into an HTML internet document and such graphics aid in teaching, the numbers and complexity of graphics had to be kept to a minimum. Each time a graphic is uploaded, a great amount of lag time is

created, especially if the users are running the tool on an older machine. This lag time generates undue waiting for the user and might lead to distraction and eventually disuse. As a result, only the most vital images have been included in the tool. Overall, the tool has been designed to make the learning experience easy, interesting, and not very time consuming. The tool allows students to access information quickly and presents it in an ordered and coherent way. Though there is an emphasis on chemistry, several other fields are represented either explicitly or implicitly in the text of the case study.

Finally, the tool allows the teacher using it enough freedom to use the tool to supplement the learning process. It is ideal for all first year chemistry classes as well as other types of classes. With the addition of small assignments and worksheets each professor can customize his or her students' use of the tool to accomplish the desired goals. The tool is flexible enough to accommodate many curriculums and easy enough to understand to be used by all students, no matter how computer literate they may be.

## CHAPTER 3

### ASSESSMENT OF THE COMPUTER TOOL

#### 3.1 Assessing the Computer Tool

##### 3.1.1 Survey Packet

In order to assess the effectiveness of the teaching tool and determine what revisions would be necessary to make it complete, a panel of experts from academia and industry was selected and asked to work through the case study. In order to develop the survey instrument for this portion of the thesis, Professor Patrick Beaton was asked to assist and supplement the information used to formulate the first questionnaire, Figure 1. Professor Beaton holds a Ph. D from Rutgers University. He is a nationally known researcher in the area of public policy analysis, land use planning, and transportation demand forecasting. His current studies include the design of performance evaluation criteria for the enforcement of the Federal Clean Air Act of 1990 and the modeling of the cost constrained demand for infrastructure by corporate aviation. For this thesis, Professor Beaton assisted in the formulation of the questions and the structure of the interview process as well as the choice of experts to be used on the panel. He also suggested that the survey process be field-tested on two test subjects who would be qualified to assess the tool but who were not on the panel of experts. In this way, the actual survey process would run more smoothly.

### **3.1.2 The Field-Test Subjects**

Two professional engineers with a strong chemistry background, working knowledge of environmental issues, and some understanding of the stratospheric ozone depletion problem were sought to act as the field-test subjects. Field-tester #1 is Mr. Douglas A. Kretkowski. Mr. Kretkowski currently works at the New Jersey Technical Assistance Program in Newark, New Jersey, where he is employed as a Pollution Prevention Analyst. He received a Bachelor of Science in Chemical Engineering from the New Jersey Institute of Technology in 1995.

Field-tester #2 is Mr. Jeffrey T. Lewis. Mr. Lewis also currently works at the New Jersey Technical Assistance Program in Newark, New Jersey, where he is employed as a Pollution Prevention Analyst. He received a Bachelor of Science in Chemical Engineering from Princeton University in 1995. As part of their work, both field-testers advise manufacturers in New Jersey about pollution prevention practices.

Both field-testers agreed to work through the tool and answer the survey questions to the best of their ability.

### **3.1.3 The Experts on the Panel**

A panel of four experts was assembled to work through the tool. The panel was designed to have a balanced mix of experts who would be able to give a comprehensive interdisciplinary evaluation of the tool. The four experts are: Dr. John Opie, Dr. Glen Marie Lange, Dr. Joseph Bozzelli, and Mr. Mike Wallace.

Dr. John Opie holds a Ph. D from the University of Chicago and is a Distinguished Professor of History at the New Jersey Institute of Technology where he

teaches environmental history and policy. Director of the Graduate Program in Environmental Policy Studies at NJIT and a past Fellow of the National Humanities Center, he has written or co-authored *Energy and American Values* (1982), *The Law of the Land* (1987), *Ogallala: Water for a Dry Land* (1993) and is currently writing an environmental history textbook. He is founding editor of the professional journal, *Environmental History Review*, and founding president of the American Society for Environmental History. Other research and publications are in climate change, technology transfer, wilderness protection, landscape aesthetics, and global sustainability.

Dr. Glenn Marie Lange holds a Ph. D in Economics from New York University received in 1989. Dr. Lange currently works as a professor of Environmental and Natural Resource Economics at the New Jersey Institute of Technology in Newark, New Jersey. Dr. Lange has published numerous articles related to various fields of environmental economics in conference proceedings and scholarly journals.

Mr. Mike Wallace holds a BS in Chemical Engineering. Mr. Wallace is the Associate Director of Environmental Affairs at Sandoz Pharmaceutical Company in New Jersey.

Dr. Joseph W. Bozzelli holds a Ph. D in Physical Chemistry from Princeton University received in 1972. Dr. Bozzelli is a Distinguished Professor of Chemistry at the New Jersey Institute of Technology in Newark, New Jersey. His research interests include analysis of elemental reaction pathways, thermochemical modeling of atmospheric chemistry and combustion processes, determination of thermochemical



parameters, and thermal treatment of hazardous materials. In addition, Dr. Bozzelli has published numerous articles related to his research interests in conference proceedings and scholarly journals.

#### **3.1.4 The Survey Instrument**

It was decided that both open-ended and close-ended questions were required to fully evaluate the tool. The open-ended questions were free response while the close-ended questions were eventuated on a Likert scale.

The questionnaires were designed to gather responses from the panel about their individual areas of expertise. Each was given a packet of questions and asked to work through the tool. The first page of the packet, titled “Objective of the Project,” Figure 1, is included along with two other representative pages from the packet, Figure 2 and Figure 3. The objective page is designed to give the expert an idea of what the goals of the computer tool is and why they were asked to participate in the survey process.

The first eighteen pages of the survey are identical to Figure 2 except for the headers. Figure 2 is the first questionnaire page. Each subsequent page is headed with the appropriate page number which corresponds to the pages of the narrative in the case study. The last page of the survey is shown in Figure 3. This page consists of five statements which ask for a Likert type response. These questions are used to gather information about the experts’ general impressions of the tool.

The sample survey pages are given below:

### Objective of the Project

The attached sets of surveys are designed to gather information about a computerized teaching tool (tool). As an expert in one of the fields of study related to the tool, you have been asked to use the tool to work through the stratospheric ozone layer depletion case study and answer the survey questions about the material contained therein.

The tool has been designed to teach first year chemistry students about the depletion of the stratospheric ozone layer by Chlorofluorocarbons (CFCs). An interdisciplinary case-study about the evolution of the problem and its solutions was developed to be used as the foundation for the tool. The case-study will provide the student with an in-depth and balanced understanding of how experts examine problems. Though the typical chemistry curriculum provides all the pertinent information related to chemistry, the tool knits together the important chemical principles with pertinent facts from the fields of economics, history, and politics. Also, the tool will present the information in an easily accessible and interesting manner, thus facilitating the education process. The tool is intended to give a broad and well-rounded sense of the problem and the process of finding the solutions. Though the tool will be used in a chemistry class, it shows the student the interconnectedness of the various subject areas. By showing the shift in thought that occurred concerning CFCs, the case-study can help to raise the awareness of the chemistry students as well as explain the transformation of the views of science and the industrial community. Please take your time exploring the tool and answering the attached surveys that apply to your field of study.

These surveys are also to be used in the assessment portion of a masters thesis. Each expert has been asked to answer questions about their field of study only. It would be appreciated if you could please provide some demographic information before starting the actual survey. This information will be kept confidential and will be used to help in the assessment process.

Name: \_\_\_\_\_

Position: \_\_\_\_\_

Degree: \_\_\_\_\_

**Figure 2** Objective of the Project

### Historical Overview-- The Timeline

1) Please indicate what material should be added to this page.

2) Please indicate what material should be deleted from this page.

3) The wording and figures on this page accomplish the project's intended goal.

**Strongly Disagree**     **Disagree**     **Neutral**     **Agree**     **Strongly Agree**     **No Opinion**

4) The concepts presented on this page effectively accomplish the project's intended goal.

**Strongly Disagree**     **Disagree**     **Neutral**     **Agree**     **Strongly Agree**     **No Opinion**

Figure 3 Historical Overview--Timeline

### Evaluation of the Computer Tool

For each of the following statements, mark the response which most closely represents your opinion. Please choose only one response to each statement. The computerized case study teaching tool will simply be referred to as the tool, from this point forward.

1) The tool was useful.

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Strongly Disagree</b>	<b>Disagree</b>	<b>Neutral</b>	<b>Agree</b>	<b>Strongly Agree</b>	<b>No Opinion</b>

2) The tool presented the subject matter in a way that was easy to understand.

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Strongly Disagree</b>	<b>Disagree</b>	<b>Neutral</b>	<b>Agree</b>	<b>Strongly Agree</b>	<b>No Opinion</b>

3) The material presented by the tool was well organized.

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Strongly Disagree</b>	<b>Disagree</b>	<b>Neutral</b>	<b>Agree</b>	<b>Strongly Agree</b>	<b>No Opinion</b>

4) The graphics in the tool were used effectively.

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Strongly Disagree</b>	<b>Disagree</b>	<b>Neutral</b>	<b>Agree</b>	<b>Strongly Agree</b>	<b>No Opinion</b>

5) The tool made accessing the information easy.

<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Strongly Disagree</b>	<b>Disagree</b>	<b>Neutral</b>	<b>Agree</b>	<b>Strongly Agree</b>	<b>No Opinion</b>

Other Comments:

**Figure 4** Evaluation of the Computer Tool

## CHAPTER 4

### RESULTS AND CONCLUSIONS

#### 4.1 Field-Test Results

##### 4.1.1 Introduction

The two field-testers, Mr. Kretkowski and Mr. Lewis, completed the survey in approximately one hour. During the interview, they did not ask questions or make comments. The results of this surveys are listed in the following sections

##### 4.1.2 Survey Question 1

Question one of the survey states, “Please indicate what material should be added to this page.” Both Mr. Kretkowski and Mr. Lewis felt specific elements should be added to the tool to make it more complete and more understandable to students.

Mr. Kretkowski, for example, felt that more pictures, graphics and examples would be very useful. On pages 1, 2, 3, 6, 7, 8 and 9 he felt that a graphic could augment the understanding of the students. Mr. Lewis felt that more information should be included on pages 12 and 13 about temperature inversion, and seasonal variability of the ozone hole. These topics would allow for a better understanding of the problem and allow students to gain a better feel for the problem.

##### 4.1.3 Survey Question 2

Question two of the survey states, “Please indicate what material should be deleted from this page.” Both Mr. Kretkowski and Mr. Lewis stated that sections should be deleted from the historical overview/timeline. They felt that the timeline was complete but might

lose and/or confuse the students. Either information needed to be deleted or a better presentation style found and implemented. Other than that, Mr. Lewis felt that some of the early material on page 3 needed to be tied back to the CFC topic or deleted from the tool.

#### 4.1.4 Survey Questions 3

Question three of the survey states, “The wording and figures on this page accomplish the project’s intended goal.” This statement is followed by a Likert scale which the subject was asked to complete. The Likert scale responses were as follows: strongly disagree, disagree, neutral, agree, strongly agree, and no response. The responses for Mr. Kretkowski and Mr. Lewis are given in Table 1 below.

**Table 1** Field-tester’s Evaluation of the Wording and Figures

Survey Page	Mr. Kretkowski	Mr. Lewis
Timeline	Strongly agree	Agree
Page 1 of 17	Agree	Neutral
Page 2 of 17	Strongly agree	Neutral
Page 3 of 17	Strongly agree	Neutral
Page 4 of 17	Strongly agree	Agree
Page 5 of 17	Agree	Neutral
Page 6 of 17	Strongly agree	Agree
Page 7 of 17	Strongly agree	Agree
Page 8 of 17	Strongly agree	Strongly agree
Page 9 of 17	Strongly agree	Strongly agree
Page 10 of 17	Strongly agree	Strongly agree
Page 11 of 17	Strongly agree	Strongly agree
Page 12 of 17	Strongly agree	Strongly agree
Page 13 of 17	Strongly agree	Strongly agree
Page 14 of 17	Strongly agree	Strongly agree
Page 15 of 17	Strongly agree	Strongly agree
Page 16 of 17	Strongly agree	Strongly agree
Page 17 of 17	Strongly agree	Strongly agree

#### 4.1.5 Survey Questions 4

Question four of the survey states, “The concepts presented on this page effectively accomplish the project’s intended goal.” This statement is followed by a Likert scale which the subject was asked to complete. The Likert scale responses were as follows: strongly disagree, disagree, neutral, agree, strongly agree, and no response. The responses for Mr. Kretkowski and Mr. Lewis are given in Table 2 below.

**Table 2** Field-tester’s Evaluation of the Content

Survey Page	Mr. Kretkowski	Mr. Lewis
Timeline	Agree	Strongly agree
Page 1 of 17	Neutral	Strongly agree
Page 2 of 17	Neutral	Strongly agree
Page 3 of 17	Neutral	Strongly agree
Page 4 of 17	Agree	Strongly agree
Page 5 of 17	Neutral	Agree
Page 6 of 17	Agree	Strongly agree
Page 7 of 17	Agree	Strongly agree
Page 8 of 17	Strongly agree	Strongly agree
Page 9 of 17	Strongly agree	Strongly agree
Page 10 of 17	Strongly agree	Strongly agree
Page 11 of 17	Strongly agree	Strongly agree
Page 12 of 17	Strongly agree	Strongly agree
Page 13 of 17	Strongly agree	Strongly agree
Page 14 of 17	Strongly agree	Strongly agree
Page 15 of 17	Strongly agree	Strongly agree
Page 16 of 17	Strongly agree	Strongly agree
Page 17 of 17	Strongly agree	Strongly agree

#### 4.1.6 Overall Evaluation of the Computer Tool Page

The final page of the survey, FIGURE 4 above, asks the participants to evaluate the tool as a whole. Once again, each numbered statement was followed by a Likert scale which the subject was asked to complete: The responses for Mr. Kretkowski and Mr. Lewis are given in Table 3 below.

**Table 3** Field-tester's Opinion of the Overall Tool

Survey Questions	Mr. Kretkowski	Mr. Lewis
1) Tool was useful	Strongly Agree	Agree
2) Easy to understand	Agree	Agree
3) Well organized	Strongly Agree	Agree
4) Effective use of graphics	Strongly Agree	Agree
5) Easy information access	Strongly Agree	Agree

As can be seen from Table 3, both Mr. Kretkowski and Mr. Lewis gave the tool positive marks. Mr. Kretkowski made no additional comments beyond his response to the five statement. Mr. Lewis made an additional comment which has been given below. He wrote, "It tells a good story--good mixing of chemistry, economics, and politics."

## 4.2 Expert Panel Results

### 4.2.1 Introduction

The four experts who comprised the panel, Dr. Opie, Dr. Lange, Dr. Bozzelli, and Mr. Wallace, were given the survey packet and asked to work through the tool. It took Dr. Opie and Mr. Wallace approximately one hour to finish the entire survey. Dr. Lange and Dr. Bozzelli took approximately an hour and a half to complete the survey.

During the interview process, the author watched and noted whether any statements were made or questions asked. Dr. Opie made comments, asked questions, and gave constructive criticisms related to the topics contained in the pages he was reviewing. Dr. Lange expressed her criticisms and preferences for different portions of the tool. Also, she asked for further information concerning subjects presented in the



material. Mr. Wallace did not ask questions or make spoken comments about the tool as he worked through it. Dr. Bozzelli said nothing while he worked through the tool. All of the experts made comments about cosmetic changes such as spelling and display problems. These correction will be made by the author but not discussed in the evaluation section below. Any other comments that were made pertaining to the tool were entered on the appropriate portion of the survey by the expert making the comment. These will be discussed further in the sections which follow.

The results of this survey are listed in the following sections. Each question of the survey is addressed individually and in the order it was asked. The experts' overall assessment of the tool will be handled at the end of this section.

#### **4.2.2 Survey Question 1**

Question one of the survey states, "Please indicate what material should be added to this page." A summary of the experts' responses is given below.

Dr. Opie's comments concerning the additions began with the timeline. He felt that more interpretive material should be included. Also, he felt the students should be given more of a connection to the underlying text. On pages three, and five, professor Opie felt that the material should be tied back into the overall discussion of CFCs. He also felt that examples of the chemical principles and down to earth explanation of some of the numbers presented in the case study would help the students to better understand the topic. Finally, he suggested that the material on Rowland and Molina be expanded and highlighted.

Dr. Lange had several additions which she felt would make the tool more easily understood by the students. First, she felt that the overview / timeline should be broken into the same sections that the text is broken into. In this way the students will have a better understanding of what types of materials are being discussed in each section. The next addition which Dr. Lange felt was necessary appears on page five and six. She felt that the discussion about the periodic table should be accompanied by a copy of the table which appears on page four. On page nine, she felt a picture of the methane building block would be very helpful to students. On the following pages, she thought that pictures of CFC-11 and CFC-12 would give the students a better mental picture of the chemicals in question. She felt that more examples of the material on page fourteen was necessary to give the students a good economic perspective. Finally, on page seventeen she felt that a discussion of why the global consensus was reached would make the case study more complete and comprehensive.

Mr. Wallace had two suggestions for additions to the tool. He felt that a paragraph at the very beginning briefly explaining what was coming in the subsequent pages would be helpful to the students. In this paragraph, he also suggested that some reasoning behind why ozone depletion and chemistry were linked together. Mr. Wallace's other addition dealt with the addition of a figure on page ten to help the student visualize what a molecule of methane might look like.

In relation to the material which needed to be added to the tool, Dr. Bozzelli made a general comment about the overall content. He wrote that, "In general, this is not as accurate as any typical chemistry text." He also made comments and small corrections

throughout the text. All of the additions which Dr. Bozzelli notes are intended to increase the usability and accuracy of the tool. In further discussion with Dr. Bozzelli, he made it clear that a typical chemistry text takes years to be written. Also, he said that any text needs to be reviewed by Ph. D level chemists to assure accuracy and completeness. He did not feel that the two semesters spent building the case study were enough to make this a “good” virtual textbook. As the teaching tool that was developed is not a textbook, it was decided that this type of rigor was not necessary. All the corrections which were suggested by Dr. Bozzelli were entered into the case study.

Besides the correctness issue, Dr. Bozzelli did give other suggestions about material to be added. On page two he felt that a discussion of the atomic mass of protons and neutrons was necessary to make this page complete. On page three, he noted that a definition of a mole was necessary to the discussion. Also on this page, he felt that more information about the ideal gas law was necessary to give a fully developed picture of what actually happens under changing conditions of temperature, pressure, and volume. On page five, Dr. Bozzelli wrote that, “The material is just presented.” He felt that the filling of energy levels should be explained more fully. On pages thirteen, fourteen, and fifteen, Dr. Bozzelli felt that figures could more effectively illustrate the material. In the case of the Chapman cycle, he thought that the figure was necessary to help the students visualize what is happening. Finally, on page sixteen, Dr. Bozzelli felt that an explanation of the figure was necessary to allow the students to fully understand what is being presented.

All of the additions which the experts suggested were reviewed by the author. Every attempt was made to incorporate the changes which were suggested into the tool. The results of this question are discussed further in section 4.3 conclusions.

#### **4.2.3 Survey Question 2**

Question two of the survey states, “Please indicate what material should be deleted from this page.” A summary of the experts’ responses is given below.

Dr. Opie’s comments concerning the material to be deleted was related to the timeline. He felt that there was too much information included in the overview. In his opinion, the amount of material would confuse the student if they even bothered to read through all of it.

Dr. Lange did not feel that any of the material presented in the case study should be deleted. However, she felt that the timeline should be reorganized so that the material could be more easily understood and accessed by students.

Mr. Wallace did not make any suggestions in this area. He felt that all the material was interesting and appropriate to the discussion.

Dr. Bozzelli did not make any specific notes about material which needed to be deleted from the tool. However, his comments listed above do suggest that he feels that the technically incorrect statements need to be corrected.

All of the deletions which the experts suggested were reviewed by the author. Every attempt was made to rework the tool to reflect the changes which the experts had suggested. The results of this question are discussed further in section 4.3 below.

#### 4.2.4 Survey Questions 3

Question three of the survey states, “The wording and figures on this page accomplish the project’s intended goal.” At the time of the interview, the experts were told that this question referred to the way the material was presented on each page. The statement is followed by a Likert scale which the subject was asked to complete. The Likert scale responses were as follows: strongly disagree, disagree, neutral, agree, strongly agree, and no opinion. If a subject did not mark a response, the entry was marked as no response. The responses for Dr. Opie, Dr. Lange, Dr. Bozzelli, and Mr. Wallace are given in Table 4 below.

**Table 4** Experts’ Evaluation of the Wording and Figures

Survey Page	Dr. Opie	Dr Lange	Dr. Bozzelli	Mr. Wallace
Timeline	Disagree	Strongly agree	Agree	Strongly agree
Page 1 of 17	Strongly agree	Strongly agree	Agree	Agree
Page 2 of 17	Agree	Strongly agree	Agree	Agree
Page 3 of 17	Agree	Strongly agree	No response	Agree
Page 4 of 17	Strongly agree	Strongly agree	Agree	Agree
Page 5 of 17	Agree	Neutral	No response	Agree
Page 6 of 17	Agree	Strongly agree	Agree	Agree
Page 7 of 17	Strongly agree	Strongly agree	Neutral	Strongly agree
Page 8 of 17	Strongly agree	Strongly agree	Neutral	Strongly agree
Page 9 of 17	Strongly agree	Strongly agree	Neutral	Strongly agree
Page 10 of 17	Strongly agree	Strongly agree	No response	Strongly agree
Page 11 of 17	Agree	Strongly agree	Agree	Strongly agree
Page 12 of 17	Strongly agree	Strongly agree	Disagree	Strongly agree
Page 13 of 17	Strongly agree	Strongly agree	Agree	Strongly agree
Page 14 of 17	Agree	Strongly agree	Agree	Strongly agree
Page 15 of 17	Strongly agree	Strongly agree	No response	Strongly agree
Page 16 of 17	Strongly agree	Strongly agree	No response	Strongly agree
Page 17 of 17	Agree	Strongly agree	Agree	Strongly agree

#### 4.2.5 Survey Questions 4

Question four of the survey states, “The concepts presented on this page effectively accomplish the project’s intended goal.” At the time of the interview, the experts were told that this question referred to the content of the material present on each page. The statement is followed by a Likert scale which the subject was asked to complete. The Likert scale responses were as follows: strongly disagree, disagree, neutral, agree, strongly agree, and no opinion. If a subject did not mark a response, the entry was marked as no response. The responses for Dr. Opie, Dr. Lange, Dr. Bozzelli, and Mr. Wallace are given in Table 5 below.

**Table 5** Experts’ Evaluation of the Content

Survey Page	Dr. Opie	Dr Lange	Dr. Bozzelli	Mr. Wallace
Timeline	Disagree	Strongly agree	Agree	Strongly agree
Page 1 of 17	Strongly agree	Strongly agree	Agree	Agree
Page 2 of 17	Agree	Strongly agree	Agree	Agree
Page 3 of 17	Agree	Strongly agree	No response	Agree
Page 4 of 17	Strongly agree	Strongly agree	Agree	Agree
Page 5 of 17	Agree	Neutral	No response	Agree
Page 6 of 17	Agree	Strongly agree	Agree	Agree
Page 7 of 17	Strongly agree	Strongly agree	Neutral	Strongly agree
Page 8 of 17	Strongly agree	Strongly agree	Neutral	Strongly agree
Page 9 of 17	Strongly agree	Strongly agree	Neutral	Strongly agree
Page 10 of 17	Strongly agree	Strongly agree	No response	Strongly agree
Page 11 of 17	Agree	Strongly agree	Agree	Strongly agree
Page 12 of 17	Strongly agree	Strongly agree	Disagree	Strongly agree
Page 13 of 17	Strongly agree	Strongly agree	Agree	Strongly agree
Page 14 of 17	Agree	Strongly agree	Agree	Strongly agree
Page 15 of 17	Strongly agree	Strongly agree	No response	Strongly agree
Page 16 of 17	Strongly agree	Strongly agree	No response	Strongly agree
Page 17 of 17	Agree	Strongly agree	Agree	Strongly agree

#### 4.2.6 Overall Evaluation of the Computer Tool Page

The final page of the survey, FIGURE 4 above, asks the participants to evaluate the tool as a whole. The responses for Dr. Opie, Dr. Lange, Dr. Bozzelli, and Mr. Wallace are given in Table 6 below.

**Table 6 Experts' Opinion of the Overall Tool**

Survey Questions	Dr. Opie	Dr Lange	Dr. Bozzelli	Mr. Wallace
1) Tool was useful	Strongly agree	Strongly agree	Neutral	Strongly agree
2) Easy to understand	Strongly agree	Strongly agree	Neutral	Strongly agree
3) Well organized	Strongly agree	Strongly agree	Neutral	Strongly agree
4) Effective use of graphics	Agree	Strongly agree	Neutral	Strongly agree
5) Easy information access	Strongly agree	Strongly agree	Neutral	Strongly agree

Table 6 shows that both Dr. Lange and Mr. Wallace felt that the tool accomplished each area very effectively. Dr. Opie agreed with this assessment except for the use of graphics in the tool. He felt that more graphics would aid in the education process and could make the tool better. Dr. Bozzelli was the dissenting voice on the panel. He was neutral to all five of the questions.

The last element which can be reported from the surveys is the experts responses which were written under the "other comments" section. Dr. Bozzelli did not make any additional comments in this section. Dr. Opie wrote, "watch typos on each page." Dr. Lange wrote, "I learned a lot and it was fun!" Finally, Mr. Wallace simply wrote, "Wonderbar!"

### 4.3 Conclusions

After reviewing the comments of the experts, several things were clear. First, all cosmetic errors needed to be removed from the tool. This meant that any typographical errors or graphic mistakes would have to be removed. This was not a problem. The actual structural changes and additions, however, were a more serious problem.

Of all the corrections or changes suggested by the panel of experts, the most common related to the overview. Though the experts disagreed as to the extent of the changes which needed to be made, it was clear that something needed to be done. As it stood, that section was confusing and contained too much structureless information.

The other addition which the experts agreed upon related to graphics. It would be necessary to add as many graphics as possible without making the tool so graphics oriented that it became inaccessible to students using slow computers or on slow networks. Only the most important and effective graphics would be added to those sections which needed these types of additions.

In conjunction with the graphics, the experts felt that more examples and definitions of terms throughout the tool would help the students understand the material.

Finally, each expert had input about smaller corrections which have been listed above. As was stated earlier, every attempt was made to incorporate the experts suggestions into the tool as long as the suggestions did not compromise the ability of the tool to function as a computer tool which needs to be used by students with varying levels of technology and technical sophistication.



The next and final chapter, chapter five contains a print-out of the final version of the tool. Along with this is a discussion of the changes which were made to the earlier version printed in section 2.2 of the thesis.

## **CHAPTER 5**

### **FINAL REVISIONS**

#### **5.1 Final Revisions to the Tool**

##### **5.1.1 Introduction to the Final Computer-aided Teaching Tool**

It is the hope of the author that all the changes which have now been made will make the final version of the tool more effective as a teaching tool. The reader should understand that the computer-aided tool is meant as an addition and not a replacement to existing curriculum. Also, many more things would be possible if the constraints placed upon the author were different.

Again, the reader should keep in mind that the tool being viewed below is meant to be used on a computer distributed through a network or via the World Wide Web. Moreover, the tool was designed to allow the student to complete the entire learning process in approximately an hour and a half to two hours. As a result, many graphics which might have aided in the learning process have been omitted from the tool. Also, some related topics and information have not been included or have been placed on subordinate pages. In this way, it is the author's hope that the tool will be most effectively used by the largest number of teaching professionals. The final goal of this thesis is to make the best end-product available to the most people.

##### **5.1.2 The Final Computerized Tool Print-out**

The following pages contains the final printed version of the computer-aided teaching tool.

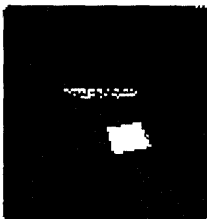
## Case Studies

Please choose one of the case-studies listed below.



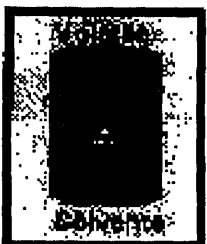
Click above to access the [Stratospheric Ozone Depletion Case Study](#)

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Click above to access the [Printing Inks Case Study](#)

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Click above to access the [Volatile Solvent Elimination Case Study](#)

---

A tutorial has been provided to help the user become familiar with how to use the computer tool. To view the tutorial, return to the title screen and click on the bookcase icon.

[Return To Title Screen](#)

## Stratospheric Ozone Layer Depletion Case Study

This is the introductory screen of the Stratospheric Ozone Layer Depletion case study. We suggest that you begin with the overview. However, for your convenience, links to other portions of the case study have been provided. Since the case study is interdisciplinary, it is difficult to separate any one field from the others. As a result, subject areas may overlap within the body of the case study.

The six icons shown below are provided to assist the users as they work through the case study. Each icon has two purposes. First, the icons represent a major field of study presented later in the narrative of the case study. Icons appear on the top of each page of the narrative to give the user an idea of what material will be covered on that page. Second, if the icons on this page are clicked the first page in the narrative containing material related to that icon will be accessed. More than one Icon can appear on the top of any one page. This is due to the interdisciplinary nature of the case study.

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### Begin the Case Study

---

#### The Historical Overview




---

Chemistry--The Beginning



OR



Atmospheric Chemistry

---

Economics



OR



Politics



#### The Alternatives

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The Goto page has been included to allow access to the entire case study. When the Goto arrow is clicked, a screen appears which allows access to the major areas of the case study.



*Goto anywhere in the case study*

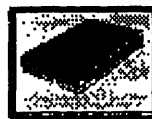
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A tutorial has been provided to help the user become familiar with how to use the computer tool. To view the tutorial, return to the title screen and click on the bookcase icon.

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[Return To Case Study Selection](#)

[Return To Title Screen](#)



# The Overview & Timeline

## Tracing Chemistry and the Depletion of the Stratospheric Ozone Layer By Chlorofluorocarbons

The following is an overview of the entire case study. Each page is listed separately and is accompanied by one or more icons which represents the major fields of study covered on that page. If the page numbers are clicked, the appropriate page will be accessed. Important dates which appear on each page are also listed under each section. If any of the dates listed are clicked, the appropriate page will be accessed. By clicking the phrase, "Additional Dates of Interest," a page with more information about other dates pertaining to that page will appear. Finally, a brief synopsis of the material contained on that page is also included for each page designation. Clicking the word synopsis will access the text.

---



### Page 1 of 17

15th Century— Leonardo DeVinci writes that air has several constituents, one of which supports combustion.

17th Century-- Robert Boyle provides the first operational definition of an element. Also, Boyle observes that for a given number of moles of gas molecules, the pressure is inversely proportional to the volume if the temperature is held constant.

### Synopsis

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### Page 2 of 17

1775-1776— Antoine-Laurent Lavoisier first recognizes oxygen as an element.

### Synopsis

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## Page 3 of 17

1800— Jacques Charles observes that, for a given number of moles of gas, the volume is directly proportional to the absolute temperature if the pressure is held constant.

1811— Amedeo Avogadro proposed that equal volumes of a gas at constant pressure and temperature have an equal number molecules.

### Synopsis

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## Page 4 of 17

Spring 1851— Dr. John Gorrie invents the first working refrigerator.

1871— Mendeleev's periodic table is published in English. Many empty spaces appear where soon-to-be discovered elements he placed.

### Synopsis

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## Page 5 of 17

### Synopsis

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## Page 6 of 17

### Synopsis

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## Page 7 of 17

### Synopsis

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## Page 8 of 17

June, 1918—General Motors begins manufacturing refrigerators for public consumption.

December 31, 1928— The first patent is given for the formula for chlorofluorocarbons (CFC).

April 1930— Midgley makes a presentation demonstrating the safety of CFCs.

August 27, 1930— General Motors and DuPont enter into a joint venture to produce and market CFCs.

### Synopsis

---



## Page 9 of 17

### Synopsis

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## Page 10 of 17

1932— The Carrier Corporation markets the first self-contained household air-conditioning unit. "The Atmospheric Cabinet"

### Synopsis

---



## Page 11 of 17

September 8, 1941--Thomas Midgley Jr. receives the American Chemical Society's Priestly award for outstanding creativity in the field of chemistry.

1956-- America's first air-conditioned mall opens in Edina, Minnesota.

December 1973-- Rowland and Molina theorize that CFCs can destroy the ozone in the stratosphere.

### Additional Dates of Interest

### Synopsis

---



### Page 12 of 17

December 1974—The first government hearings are held on the CFC-ozone theory in the United States.

#### Additional Dates of Interest

#### Synopsis

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### Page 13 of 17

August 1981—NASA scientist Donald Heath announces that satellite records show global ozone levels have declined 1 percent.

#### Additional Dates of Interest

#### Synopsis

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### Page 14 of 17

#### Synopsis

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### Page 15 of 17

September 1987—The Montreal Protocol is signed, calling for eventual worldwide CFC reductions of 50 percent.

#### Additional Dates of Interest

#### Synopsis

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### Page 16 of 17



## Synopsis

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## Page 17 of 17

1990-1993— DuPont's research and development arm produces substitutes for CFCs. These include partially hydrogenated chlorofluorocarbons (HCFC) and totally hydrogenated chlorofluorocarbons (HFC).

## Additional Dates of Interest

## Synopsis

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Home Case Study Main Menu

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*Goto anywhere in the case study*

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## Summaries of the Pages

Below are summaries of each of the seventeen pages of the case study. They are accessed directly by clicking the appropriate chapter synopsis button in the overview.

---

### Synopsis of Page 1

The following pages will present a case study concerning the depletion of the stratospheric ozone layer by chlorofluorocarbons (CFCs). The first portion of the case study focuses on basic chemical principles necessary to understand the CFC story. Later, many other elements will be incorporated into the narrative to provide a complete and balanced view of the problem.

[Back to the Overview](#)

---

### Synopsis of Page 2

The material on page two relates to atomic structure. This page provides a foundation for much of the material which will follow.

[Back to the Overview](#)

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### Synopsis of Page 3

Page three opens with a discussion of Charles' Law. Next, Avogadro's Law is presented and used to unify Boyle's, Charles', and Avogadro's law into the Ideal Gas Law. This page closes with a discussion of the Ideal Gas Law.

[Back to the Overview](#)

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### Synopsis of Page 4

The first part of page four discusses the first refrigerator which was developed by Dr. John Gorrie. The remainder of the page discusses the early periodic table. A copy of the modern periodic table is included on this page.

[Back to the Overview](#)

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### Synopsis of Page 5

Before dealing more extensively with the periodic table, this page discusses the electronic configurations of the elements. The text then goes on to explain how the energy levels of different atoms are filled in a particular order to give the periodic table its unique shape.

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[Back to the Overview](#)

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### **Synopsis of Page 6**

Page six explains the families of elements found in the periodic table. Each family has unique chemical and physical properties which help chemists delineate the families.

[Back to the Overview](#)

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### **Synopsis of Page 7**

Page seven briefly explains chemical bonding before broadening the discussion to the progress of chemistry as a science.

[Back to the Overview](#)

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### **Synopsis of Page 8**

This is the first time something other than chemistry is discussed. This page looks at the entrance of corporations, such as General Motors, into the world of organized science. The main focus of this page is a discussion of how scientists working for General Motors developed the first CFCs.

[Back to the Overview](#)

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### **Synopsis of Page 9**

Page nine focuses on the marketing of CFCs under the name Freon. It provides an example of the naming system as well as some pictures of the most common CFCs.

[Back to the Overview](#)

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### **Synopsis of Page 10**

Page ten presents the characteristics of the class of chemicals known as CFCs.

[Back to the Overview](#)

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### **Synopsis of Page 11**

Page eleven looks at the spread of CFCs throughout industry. Due to their chemical usefulness and inexpensive cost, CFCs seemed to be the perfect chemical for many industrial needs.

[Back to the Overview](#)

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## Synopsis of Page 12

This page begins the discussion of atmospheric chemistry. It opens with a description of the Earth's atmosphere as well as how ozone is formed in the upper atmosphere.

[Back to the Overview](#)

---

## Synopsis of Page 13

Page thirteen describes the process of ozone destruction by CFCs. It also looks at the unique situation at the south pole where an ozone hole has formed.

[Back to the Overview](#)

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## Synopsis of Page 14

Page fourteen discusses the role of science in the debate over ozone depleting chemicals such as CFCs. Also discussed are the ways in which science can assist in the solution of the ozone depletion problem.

[Back to the Overview](#)

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## Synopsis of Page 15

The Montreal Protocol is the focus of page fifteen. Both the reasons for the original protocol as well as its amendments are given and discussed.

[Back to the Overview](#)

---

## Synopsis of Page 16

Page sixteen describes some modern monitoring tools such as satellites and ground-based ozone data collection systems. A graphic example of the ozone depletion problem is also provided.

[Back to the Overview](#)

---

## Synopsis of Page 17

The final page of the text, page seventeen, presents several alternative methods which have been used to help solve the stratospheric ozone layer depletion problem.

[Back to the Overview](#)

---

# Additional Dates of Interest

## Page 11

1958-- 90% of the theaters, 40% of restaurants, and 25% of the hotel rooms in America are air-con

1962-1966-- 75% of all new apartment buildings are equipped with air-conditioning.

1963-- 15% of the 6.5 cars in America have air-conditioning.

1971-- 58% of all American cars have air-conditioning, as do many truck cabs and other conveyanc

1972-- More than half of all residences have some form of air-conditioning.

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[Return to Overview](#)

## **Additional Dates of Interest**

### **Page 12**

**May 1975--The CFC-ozone theory is hotly debated at the American Chemical Society meeting in Philadelphia.**

**June 1975--The Natural Resources Defense Council sues the Consumer Product Safety Commission for a ban on CFCs used in aerosol spray cans.**

**June 1975--Johnson Wax, the nation's fifth largest manufacturer of aerosol sprays, announces it will stop using CFCs in its products.**

**June 1975--A government task force called IMOS defers the decision to regulate CFCs to the pending NAS report.**

**June 1975--Oregon becomes the first state to ban CFCs in aerosol sprays.**

**July 1975--The Consumer Product Safety Commission rejects the NRDC's lawsuit claiming that there is insufficient evidence that CFCs harm the ozone layer.**

**September 1976--The National Academy of Sciences releases its report verifying the Rowland-Molina hypothesis, but says government action on CFC regulations should be postponed.**

**October 1976--The Food and Drug Administration and Environmental Protection Agency propose a phase-out of CFCs used in aerosols.**

**March 1977--The United Nations Environmental Program holds the first international meeting to discuss ozone depletion.**

**May 1977--Several government agencies announce joint plans to limit the uses of CFCs in aerosols.**

**October 1978--CFCs used in aerosols are banned in the United States.**

**November 1979--A second NAS report on the CFC-ozone theory is released, putting depletion estimates at 16.5 percent and saying a "wait-and-see" approach to regulations is not practical.**

**April 1980--The EPA announces the United States' intention to freeze all CFC production at 1979 levels.**

**October 1980--The EPA, under the Carter administration, releases an Advanced Notice of Proposed Rule-making outlining plans for additional CFC regulations.**

**July 1981--Hearings are held in Washington to discuss protection of small businesses from possible new CFC regulations. Hearings are highly critical of the Advanced Notice of Proposed Rule making.**

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**[Return to Overview](#)**

## Additional Dates of Interest

### Page 13

March 1982--The NAS releases a third report on CFC-ozone and predicts eventual ozone depletion of 5 to 9 percent.

February 1984--A fourth NAS report downplays the potential harm to the ozone layer from CFCs by lowering depletion estimates to 2 to 4 percent.

October 1984--A British research group led by Joe Farman detects a 40 percent ozone loss over Antarctica during austral spring.

March 1985--The Vienna Convention, calling for additional research and exchange of information on ozone depletion, is signed by international negotiators. Negotiators fail to agree on worldwide CFC regulations.

May 1985--Farman's paper is published in *Nature*.

August 1985--NASA's Heath shows satellite photos confirming the existence of an ozone hole over Antarctica.

January 1986--EPA releases its Stratospheric Ozone Protection Plan which calls for new studies to determine whether additional CFC regulations are needed.

June 1986--Papers are published by two research groups indicating chemicals and polar stratospheric clouds are responsible for ozone losses over Antarctica.

June 1986--CFC manufacturers suggest that safe substitutes for the chemicals might be possible for a high enough price.

September 1986--A major CFC industry lobbying group announces it will support limits on CFC growth.

September 1986--The DuPont Corporation announces it will call for limits on world-wide CFC production.

December 1986--International negotiations on ozone protection resume in Geneva after a 17 month layoff. The United States proposes worldwide CFC reduction of 95 percent by the next decade.

April 1987--Under pressure from some high-level officials, the United States backs off its original position and proposes long-term CFC reductions of 50 percent.

June 1987--NASA's Heath reports satellite findings of a 4 percent ozone loss detected over a seven year period. A NASA-sponsored study called the Ozone Trends Panel is organized to review the findings.

August 1987--The McDonald Corporation announces it will no longer purchase materials which were made using CFCs to package its food products.

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## **Additional Dates of Interest**

### **Page 15**

**October 1987--The Antarctic ozone expedition ends: findings indicate that chlorine chemicals are the primary cause of ozone depletion.**

**November 1987--A scientific conference confirms the findings of the Antarctic ozone depletion expedition.**

**November 1987--United States lawmakers call for new negotiations to strengthen the Montreal Protocol.**

**February 1988--Three United States senators ask DuPont to stop making CFCs.**

**March 1988--The chairman of DuPont denies the request to stop making CFCs.**

**March 1988--The United States ratifies the Montreal Protocol in a unanimous vote.**

**March 1988--The Ozone Trends Panel announces it has found ozone losses of 1.7 to 3 percent over the Northern Hemisphere.**

**March 1988--Three weeks after refusing to stop making CFCs, the DuPont Corporation announces it will cease manufacture of the chemicals as substitutes become available.**

**April 1988--Manufacturers of plastic foam food containers announce they will stop using CFCs.**

**August 1988--The EPA orders domestic CFC reductions that mirror the terms of the Montreal Protocol.**

**October 1988--Scientists meeting in the Netherlands confirm the Ozone Trends Panel findings of ozone losses in the Northern Hemisphere.**

**March 1989--European countries and the United States agree to faster CFC reductions but developing countries oppose the new timetable citing the costs of substitutes and scientific uncertainty.**

**1990-- The United States Congress passes the amendments to the Clean Air Act. These amendments include Title VI, regulations concerning the protection of stratospheric ozone.**

**1992-- Worldwide ozone levels in the stratosphere drop to lowest levels in recorded history.**

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## **Additional Dates of Interest**

### **Page 17**

1995— Auto-makers begin installing air-conditioning units in cars which use HCFC-134a, a substitute for CFC-12.

June 10, 1995— Wal-Mart opens an experimental "environmental prototype store" designed with the latest advances in environmentally conscious building materials and techniques.

August 1995— The largest hole in the ozone over Antarctica begins to form. This is the earliest a hole has formed since recordings have been made. When its growth was complete, the hole encompassed the entire continent of Antarctica and was the largest hole ever recorded.

September 14, 1995— The CEO of Whirlpool corporation announces that the company is committed to building a large state-of-the-art plant in India to manufacture CFC-free refrigeration units.

October 6, 1995— The Environmental Council agrees to argue for tighter rules on the use and production of ozone-destroying substances at the international conference in Vienna in November.

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# Stratospheric Ozone Layer Depletion



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## Introduction

The atmosphere in which we live is vital to life on earth. It acts as both a source of raw materials and a means of waste disposal for almost every form of life on the planet's surface. The constant interchange between the atmosphere, soil, water bodies, and the living organisms on Earth keep the planet's ecosystem in balance. This balanced regulated state is maintained through a series of cycles which move resources from one living organism to another by use of solar energy and materials found in the land, sea, and air. Without these cycles, the system would lose its ability to maintain the homeostasis and the entire ecosystem would soon run down. By introducing synthetic chemicals into our environment, humans have unintentionally upset nature's balance. If we are not careful, the system may be pushed too far and so not be able to recover. If this happens, the delicate balance which the Earth has been able to maintain would be lost, perhaps, making human life no longer possible.

The following pages will present a case study concerning the depletion of the stratospheric ozone layer by chlorofluorocarbons (CFCs). The first portion of the case study focuses on basic chemical principles which are necessary to understand the CFC story. Later, many other elements, such as the economics and politics surrounding the spread and eventual ban of CFCs, will be incorporated into the narrative to provide a complete and balanced view of the stratospheric ozone layer depletion story.

In the fifteenth century, Leonardo DeVinci realized that the air he breathed was comprised of more than one gas. He also noted that one of these gasses must be responsible for combustion. At that time, the science of chemistry was in its infancy. Scientists today know that the gas DeVinci was speaking of was oxygen.

## Boyle's Law

Two hundred years later, many scientists were working to explain nature. Though chemistry had not yet become a full-fledged science, at this time, many new discoveries were being made. Many different problems confronted the scientists. All worked to delineate the constituents of the world around them while quantifying these constituents' interactions.

An important early discovery was made by Robert Boyle. It concerned how gasses act when placed under stress while holding certain variables constant. While designing vacuum pumps to remove air from vessels, he noticed something that seems quite intuitive and obvious today. If you have squeezed a sealed bag of air or a balloon, you may have noticed that it seems to push back the more you compress it. Boyle labeled this resistance, "the spring of the air" and found that he could measure it. After many experiments, Boyle saw a correlation between several of the variables. He operationalized these correlations into the law which bears his name. Boyle's law states that, for a given number of moles of gas molecules, the pressure is inversely proportional to the volume if the temperature is held constant.

What Is a Mole

Boyle' law can be expressed in a formula as follows:

If

P = pressure

V= Volume

T = Temperature

n = Number of moles of gas

k = constant of proportionality

Then  $V = k / P$  or  $VP = k$  ( for a constant T and n)

For comparing the same gas sample at constant temperature under differing conditions of volume and pressure, Boyle's law can be written as follows

$$P_1 V_1 = P_2 V_2$$

The subscripts 1 and 2 represent the different conditions

An Example of Boyle's Law

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## *What Is a Mole*

A mole is an Avogadro's number of anything. Avogadro's number is 602,200,000,000,000,000,000 or, more easily,  $6.022 \times 10^{23}$ . This means if you have  $6.022 \times 10^{23}$  apples, you would have one mole of apples. Avogadro's number is so large because it is usually used when discussing extremely small objects such as atoms. By definition, A mole of the most common carbon atoms, Carbon-12, only weighs 12 grams. That means that  $6.022 \times 10^{23}$  atoms of carbon-12 has a weigh of only 12 grams.

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## *An Example of Boyle's Law*

A child is playing with a 2 liter balloon at the beach (Pressure = 1 ATM). If the child releases the balloon what will be the volume when the pressure equals ATM?

Using the formula:

$$P_1 V_1 = P_2 V_2$$

and the information provided above:

$$P_1 = 1 \text{ ATM}$$

$$V_1 = 2 \text{ liters}$$

$$P_2 = 0.50 \text{ ATM}$$

then,

$$P_2 V_2 = P_1 V_1 \rightarrow V_2 \times 0.50 \text{ ATM} = 2 \text{ liters} \times 1 \text{ ATM}$$

Rearranging,

$$V_2 = (1 \text{ ATM} \times 2 \text{ liters}) / 0.50 \text{ ATM}$$

therefore,

$$V_2 = 4 \text{ liters}$$

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## Stratospheric Ozone Layer Depletion



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### Atomic Structure

In 1773 Joseph Priestly isolated oxygen gas. A few years later, Antoine-Laurent Lavoisier recognized oxygen as an element. He was the first person to give a practical definition of an element. An element is a substance which cannot be broken down into simpler substances by chemical processes. Even if elements are physically separated, there will come a point at which there is only one unit representing that element. This unit is known as an atom. Atoms are the smallest unit of an element that can exist as a stable entity. Even though atoms can be broken down further, any separation past this level causes the constituent parts to lose any recognition as different elements. This idea of a basic unit of matter was important to future understanding and use of the elements. Even though many elements were identified, exactly what they were and how they interacted was not understood until the atomic model became known.

An atom is comprised of two major parts, the nucleus at the center, and the electron cloud orbiting about the nucleus. Two types of particles contribute to the nucleus, protons and neutrons. Though most of an atom's mass is contained in the nucleus, the nucleus does not contribute very much to the overall size of the atom. The radius of a typical atom is 1 to 2.5 Angstroms. The radius of a typical nucleus is only about 0.00001 Angstroms. 1 Angstrom is equal to .000001 millimeters. To help visualize this, imagine that you are standing in the middle of a golf course holding a golf ball. If that golf ball was the nucleus of an atom, the atom would extend for approximately three miles in every direction. As can be seen by this example, an atom is comprised of mostly empty space through which the electrons travel.

Protons and neutrons are almost exactly the same size and mass but protons carry a positive charge with them. The mass of atomic particles is measured in *Atomic Mass Units* or amu's. One amu is defined as exactly one twelfth the mass of a carbon atom which has six protons and six neutrons in its nucleus. By this definition, both protons and neutrons have a mass that is nearly but not exactly one amu. By definition, an Avogadro's number of protons or neutrons is equal to 1 gram.

The mass of a proton is 1.00728 amu and the mass of a neutron is 1.00867 amu. By comparison, the mass of an electron is only 0.000549 amu, about 1/1836 that of either a proton or a neutron.

Compared to these particles, the electrons that travel around the positively charged nucleus have almost no mass at all. Despite this relative lack of mass, about 0.00054 times that of a proton, electrons do have a negative charge that is equal to the positive charge of the proton.

In an atom that does not have a charge, the number of protons equals the number of electrons. In this way, the charges balance. If the number of electrons does not equal the number of protons, the atom is said to be an ion. Ions can be positively or negatively charged depending on whether there are more electrons or more protons.

This number of protons or electrons in a neutral atom is called the atomic number. Atomic numbers are important because each element has a unique number. Though the number of

neutrons in a nucleus can vary, each additional proton signifies a new element. Different from the atomic number is the atomic mass. The mass of an atom is calculated by adding the number of protons and neutrons together to come to a total. This mass can be different for different atoms of the same element depending on the number of neutrons in the nucleus. This is why the atomic mass of an atom can vary, while the atomic number remains constant. Atoms of the same element which have different atomic masses are called isotopes. These concepts of atomic number and mass will become very important later on in this discussion.

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## *Stratospheric Ozone Layer Depletion*



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### *Charles' Law*

Shifting away from a quest to understand elements back to a broader look at how things interact, brings us to the investigation of another gas law. In 1800 Jacques Charles observed that, for a given number of moles of gas, the volume is directly proportional to the absolute temperature if the pressure is held constant.

Charles' law can be expressed in a formula as follows:

If

P = pressure

V = Volume

T = Temperature

n = Number of moles of gas

k = constant of proportionality

Then  $V = kT$  (for a constant P and n)

For comparing the same gas sample at constant pressure under differing conditions of volume and temperature, Charles' law can be written as follows

$$T_1 V_2 = T_2 V_1$$

The subscripts 1 and 2 represent the different conditions

### An Example of Charles' Law

### *Avogadro Law*

In 1811, Amedeo Avogadro provided the vital third part to the view of gasses and their interactions. He proposed that equal volumes of a gas at constant pressure and temperature have an equal number of molecules.

Avogadro's law can be expressed in a formula as follows:

If

P = pressure

V = Volume

T = Temperature

n = Number of moles of gas

k = constant of proportionality

Then  $V = kn$  (for a constant P and T)



## *Stratospheric Ozone Layer Depletion*



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### *The First Refrigerator*

In the spring of 1851 Dr. John Gorrie put Gay-Lussac's variation of the ideal gas law into practice when he invented the first working refrigeration unit. Gorrie was a physician in Florida trying to combat malaria. At that time, spoiled food was suspected as a cause of the disease. Having a good knowledge of science, money to spend, and time to devote to his interest in inventing, Gorrie set to work on his idea of a 'cool box'. The would-be inventor looked at the variation of the ideal gas law that Gay-Lussac derived. In terms of practical applications, this formula says that if a gas is allowed to expand, it will consume heat from the surroundings. Gorrie reasoned that if the surroundings were isolated, the cooling effect could be utilized to produce ice, which could be used to keep food from spoiling. Using a steam pump, Gorrie assembled the first refrigeration unit.

Unfortunately, his idea was good but his design poor. His refrigerator did not have much success, but the idea of keeping things cool by utilizing the cooling power of an expanding gas would not be easily lost. Gorrie died without seeing his idea put into productive use, but he had started something which, with a little help from scientists and industrialists, would become an integral part of American life.

### *The Early Periodic Table*

Though there had been many important discoveries in chemistry over the last few hundred years, many of the facts that were proven were not linked together in any coherent way that could help move the science forward. Many elements had been identified and many chemical theories existed to explain how and why the universe acted the way it did. In 1871, Dmitri Mendeleev published a table which would help to revolutionize how chemistry was to be carried out. Mendeleev's table listed the known elements in order of ascending atomic numbers. This was not a particularly innovative idea by itself. The twist which made Mendeleev's periodic table different was that he classified the known elements into columns and rows according to their properties as well. He left many empty spaces which predicted soon-to-be discovered elements. This table helped to guide the search for new elements and directed research into a deeper understanding of the known elements and their interactions.

More than just helping to show where new elements might be found, the periodic table showed how each element should react and identified the families of elements as they are understood today. The arrangement of the elements on the periodic table is understood to be related to the number and arrangement of electrons in each element. Today, the periodic table is complete, in the sense that there are no longer any missing elements among the first 110 atomic numbers. Chemists continue to look for and create the higher atomic number elements guided by the knowledge of how many protons the new elements should contain and how these new elements will react once they are created.

## **The Periodic Table**

## *An Example of Charles' Law*

A child is playing with a 4 liter beach ball at the beach on a warm summer day ( temperature is 22 degrees Centigrade). If the child puts the ball in the shade where the temperature is only 17 degrees centigrade, what will be the volume of the ball?

Using the formula:

$$T_1 V_2 = T_2 V_1$$

and the information provided above:

$$T_1 = 22 \text{ C}$$

$$V_1 = 4 \text{ liters}$$

$$T_2 = 17 \text{ C}$$

First the temperatures must be converted to Kelvin . In this case, add 273 to the centigrade values.  $T_1 = 22 \text{ C} + 273 = 295 \text{ K}$

$$T_2 = 17 \text{ C} + 273 = 290 \text{ K}$$

then,

$$V_2 = V_1 \times T_2 / T_1 = 4 \text{ liters} \times 290 \text{ K} / 295 \text{ K}$$

Rearranging,

$$V_2 = ( 290 \text{ K} \times 4 \text{ liters} ) / 295 \text{ K}$$

therefore,

$$V_2 = 3.9 \text{ liters}$$

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## *More About Ideal Gas*

The ideal gas law assumes that gas molecules act as point masses which do not interact with one another. Unfortunately, this is not the case. Real atoms and molecules can not be so simply described. If all gasses were ideal, the equation  $PV/RT$  would always equal one for one mole of gas. When dealing with real gasses, however, this is not the case. The ideal gas law is a good approximation of how a gas will act. It can be used to predict the state of a gas under certain conditions. The deviation from the ideal state by any gas is given by  $Z$ , the compressibility coefficient.

$$Z = PV/RT$$

the coefficient  $Z$  can be used when the behavior of a real gas needs to be found more precisely than the ideal gas law can predict.

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## **The Periodic Table**

1	H																	2	He																
3	Li	4	Be											13	B	14	C	15	N	16	O	17	F	18	Ne										
11	Na	12	Mg											19	Al	20	Si	21	P	22	S	23	Cl	24	Ar										
19	K	20	Ca	21	Sc	22	Ti	23	V	24	Cr	25	Mn	26	Fe	27	Co	28	Ni	29	Cu	30	Zn	31	Ga	32	Ge	33	As	34	Se	35	Br	36	Kr
37	Rb	38	Sr	39	Y	40	Zr	41	Nb	42	Mo	43	Tc	44	Ru	45	Rh	46	Pd	47	Ag	48	Cd	49	In	50	Sn	51	Sb	52	Te	53	I	54	Xe
55	Cs	56	Ba	57	La	58	Ce	59	Pr	60	Nd	61	Pm	62	Sm	63	Eu	64	Gd	65	Tb	66	Dy	67	Ho	68	Er	69	Tm	70	Yb	71	Lu		
87	Fr	88	Ra	89	Ac	90	Th	91	Pa	92	U	93	Np	94	Pu	95	Am	96	Cm	97	Bk	98	Cf	99	Es	100	Fm	101	Mn	102	No	103	Lr		

58	Ce	59	Pr	60	Nd	61	Pm	62	Sm	63	Eu	64	Gd	65	Tb	66	Dy	67	Ho	68	Er	69	Tm	70	Yb	71	Lu
90	Th	91	Pa	92	U	93	Np	94	Pu	95	Am	96	Cm	97	Bk	98	Cf	99	Es	100	Fm	101	Mn	102	No	103	Lr

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#### *Electronic Configuration*

See the Periodic Table

Before discussing any more about the placement of elements on the periodic table, it is important to understand how the electrons circling the nucleus of the atoms are configured. Through experiments, scientists have demonstrated that the electrons are arranged into levels consisting of different shells. The electrons in the innermost shell are held most tightly by the atom. The further from the nucleus, the weaker the attraction the electron feels. It is said that an electron further from the nucleus is at a higher energy level, and subsequently, has more energy.

One important fact about energy levels is that they cannot hold an infinite number of electrons. Each level and shell has a specific maximum capacity. Also, both are most stable when full. The first level can hold up to two electrons. The second level has a capacity of eight. The number increases with each level but even so, atoms strive to have eight electrons in their outermost shell.

Something else to remember is that only the electrons in the outermost level or shell interact in chemical reactions. If the outer shell is full, there is very little chance that the atom will react with another atom. On the other hand, if an atom has only seven electrons it will try to find an additional electron or if the outer shell has only one electron, the atom will try to release that extra electron to move to the full shell one level lower. Knowing these facts will aid in the understanding of the periodic table.

#### *The Modern Periodic Table*

In a modern periodic table, the periods of the table increase unevenly as the atomic number of the elements increase. This is a result of the way in which electrons are added to the atoms. The first energy shell in each level is known as the S. It is capable of handling only two electrons. The second shell is the P and can handle six more for a total of eight in the second period. The third level has an additional set of atomic orbitals called the D shells which can hold ten more electrons. This pattern continues toward infinity. Each new level adds twice the next odd number of electrons. If each level filled uniformly, this system would be easy to follow. Unfortunately, by looking at the chart it is easy to see that this is not happening. Looking at the table shows that the progression is 2, 8, 8, 18, 18, 32, 32, and so on. This problem might seem hard to comprehend at first, but in the end, it has a very simple explanation.

#### *Filling The Electron Shells*

Atoms try to find an electronic configuration which allows them to reach the lowest energy state. This helps explain the odd progression in the periodic table as well as the reasons for the formation of molecules. As it turns out, certain electron configurations allow a lower energy state than others. The following chart shows how the different electron levels are filled to allow for this lowest energy state.

~~1 S(2)~~  
~~2 S(2) P(6)~~  
~~3 S(2) P(6) D(10)~~  
~~4 S(2) P(6) D(10) F(12)~~  
~~5 S(2) P(6) D(10) F(12)~~  
~~6 S(2) P(6) D(10) F(12)~~  
~~7 S(2) P(6) D(10) F(12)~~

By starting at the top of each column and reading diagonally to the left, it is possible to see how different levels fill in different orders. The number in parenthesis corresponds to the maximum number of electrons which can be placed in any one level.

As can be seen from the pattern of filling, it is more advantageous for an atom to fill the 4S shell before it fills the 3P shell. This deviation from the pattern allows for the odd, ever expanding, shape of the periodic table.

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# The Periodic Table

1	2											10	11	12	13	14	15	16	17	18		
H	He											Ne	Ar	Kr	Xe	Rn						
Li	Be											B	C	N	O	F	Ne					
Na	Mg											Al	Si	P	S	Cl	Ar					
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr					
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe					
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn					
Fr	Ra	Ac																				
		58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76		
		Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu							
		Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Mn	Jr	Lr							

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## *STRATOSPHERIC OZONE LAYER DEPLETION*



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*Families of Elements*

See the Periodic Table

To help understand the overall arrangement of the table, it is helpful to divide it into two groups; metals and nonmetals. Metals are usually typified by shiny, malleable, ductile substances that are eager to lose electrons. Conversely, nonmetals are brittle and try to gain electrons. The lower and further left on the table that one looks, the more the elements act like metals, while the higher and further right on the table one moves, the more the elements become nonmetals. In the center is a region of semimetallic compounds known as the metalloids. These can exhibit properties of both metals and nonmetals. Also, there are special cases on the table. Starting with period four, a group of elements appear. These are called the transition metals and all have very similar properties. This large collection of elements correspond to the filling of the D orbitals. Beginning in period six, there appears another collection of elements known as the rare earths or actinides. Their appearance here reflects the filling of the F orbitals. All of these metals have extremely similar chemical properties and are also very scarce.

Moving from these rather rare elements to ones that are encountered each day, let us look at the leftmost column of the chart. This group contains the family known as the alkali metals. This family is characterized by extremely reactive soft metals that will tend to form +1 ions. The family to their right are the alkaline earth metals. These are similar but tend to form a +2 ion.

Moving across the chart to the rightmost column, we find the family of elements known as the noble gasses. This family is characterized by their lack of reactivity. Each member of the group has a full outer shell and so is not interested in acquiring or losing electrons. These gasses are satisfied. The next column to the left contains the family known as the halogens. This family is the most reactive group of elements known. The members of this family are eager to acquire one electron and become anions with a -1 charge.

Other families on the chart are also grouped together but because their chemical and physical reactions are complex, it is difficult to make general statements about them. Those elements in the family headed by oxygen usually try to form -2 ions, those under nitrogen form -3 ions, and those under carbon form the unique group which can either be +4 or -4 ions.

Carbon is of particular interest because of its ability to combine with almost every other element as well as itself to form long chains or polymers. A polymer is a large molecule composed of a repeating sequence of chemicals bonded together.

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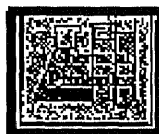
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# The Periodic Table

1	2											3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20																																																																													
H	He											Li	Be	B	C	N	O	F	Ne	Na	Mg	Al	Si	P	S	Cl	Ar	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr																																																													
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	Cs	Ba	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu																																																																								
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu														Fr	Ra	Ac	Th	Pa	U	Np	Pu	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z																																														
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### *Chemical Bonding*

It is important to understand something about chemical bonding before the discussion can move forward. All molecules are held together by bonds between atoms. A bond is an electron-static attraction between one atom and another. Two of the major types of bonding which occur are ionic and covalent bonding. In an ionic bond, one atom transfers an electron to another. When this happens, the ionic bonds are formed due to a difference in charges. The electrostatic attraction of these different charges holds the two ions together. In covalent bonding, the atoms involved do not wish to relinquish their electrons. Instead, the atoms share a portion of the electromagnetic field of the orbiting electrons. The more intense the desire for the shared electron the stronger the bond. It is this knowledge of the elements, their atomic structure, and their bonding capability that helped move chemistry forward as a science. Once the theoretical groundwork was laid, chemists were able to use this knowledge to begin synthesizing compounds found in nature as well as create many that were not.

### *The Progress of Chemistry*

This understanding of chemical reactions, the periodic table, and the interactions of gasses made many new inventions possible. With the advent of large companies, the face of chemistry changed. These corporations created research teams to develop and synthesize new chemicals and machines which would help speed the process of development. It was these research and development groups who were largely responsible for the next wave of progress and inventiveness.

Though Gorrie was not able to see his invention make its way into households we all know that it did. Thanks to other scientists and engineers, his idea was improved upon and made functional and profitable. As the demand for refrigeration grew, so did the number of chemists and engineers working on the problems.

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### *The First Chlorofluorocarbons*

In June of 1918, General Motors joined the refrigerator manufacturing industry by purchasing a small Detroit company and renaming it Frigidaire. On the surface, this does not seem to be that significant an event. However, when General Motors began manufacturing, it also began working to perfect the products it was selling. Though many other companies were in the field, few had the quality researchers that General Motors possessed. Also, the money that could be invested by this automotive giant was unparalleled.

The research team for General Motors changed the aesthetics of the early refrigerators to make them more acceptable to the consumer. This change, along with several others, improved the physical appearance and functioning of the General Motors' units. More than any other problem, the main difficulty that still remained with all refrigerators was the refrigerant used to cool the box. Ammonia, a highly toxic and potentially explosive liquid/gas was the refrigerant of choice at the time. Many research groups tried in vain to find an adequate substitute which had as good a cooling potential, was less toxic, was safe, and would not cost an exorbitant amount.

One of General Motors' most celebrated and successful researchers was a man named Thomas Midgley Jr. Midgley had invented the lead additive for gasoline as well as many other chemical innovations. When he started work on the problem of the refrigerator, no one thought that his next creation would change the world so significantly, but it did. On December 31, 1928, Frigidaire received the first patent for the class of compounds which would come to be known as chlorofluorocarbons (CFC). With this patent, the modern age of refrigerators and air-conditioning began.

In retrospect, the creation of the first chlorofluorocarbons was a momentous discovery. At the time, however, no one knew exactly what these new chemicals could be used for. Slowly, CFCs made their way into the market. Before anyone would rush to purchase and use this new chemical, many tests and studies would need to be undertaken. In April 1930 Midgley made a presentation demonstrating the safety of CFCs at the Atlanta meeting of the American Chemical Society. Midgley began by placing an empty glass jar on a table in front of the assembled crowd. Into the jar, he poured liquid CFCs, which appeared to be white and opaque. The liquid began to boil instantly as soon as it warmed to room temperature. As the vapors billowed up out of the jar, Midgley placed his face over its mouth and took a deep breath, inhaling the cold stream. He went on to explain that CFCs are non-explosive, have not harmed any animals, and except for an intoxicating effect, have no effect on humans. Moreover, CFCs are chemically inert and, most importantly, are perfect refrigerants. The crowd was thoroughly impressed. A few months later, on August 27, 1930 General Motors and DuPont entered into a partnership to produce CFCs under the trade name Freon. Scientists at the time, performed every test on CFCs that could be imagined. In the end, they were found to be safe to humans, construction materials, and the environment. Best of all, they were inexpensive and highly useful. Not until many years later did a new group of scientists find out that CFCs could be very harmful to everything on earth.

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### *Naming Freons*

As part of the marketing plan, Du Pont developed a numbering system to refer to the chlorofluorocarbons. Each species of CFC is given a number which can be used to determine its structural formula. For example, trichlorofluoromethane (CFC13) is Freon-11. (See CFC-11) The formula for decoding this system is simple.

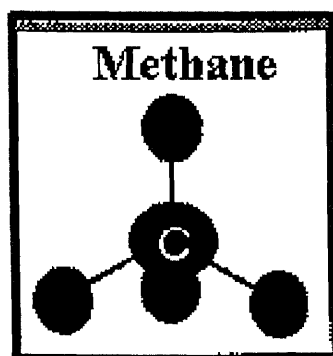
Add 90 to the Freon number and interpret the three digit result according to the following system: the left digit is the number of carbon atoms, the middle digit is the number of hydrogen atoms, and the right digit is the number of fluorine atoms. Conspicuous by its absence is chlorine. All the bonding sites that are not taken up by either fluorine or hydrogen are filled by chlorine. For example, to determine the formula for Freon-12:

$$\text{CFC-12} \rightarrow 12 + 90 = 102$$

This implies:

- 1 Carbon
- 0 Hydrogen
- 2 Fluorines

To determine the number of chlorine atoms, begin by imagining the methane building block.



Then, using the numbers from the formula above, fill in the information that is derived. Finally, count the number of vacant sites. This number equals the number of chlorine atoms. In the case of CFC-12, 1 carbon has four bonding sites. Since there are 0 hydrogen and 2 fluorines, this leaves 2 bonding sites (4 carbon - 2 fluorines). Chlorines fill the empty sites meaning there are two chlorines.

(See CFC-12)

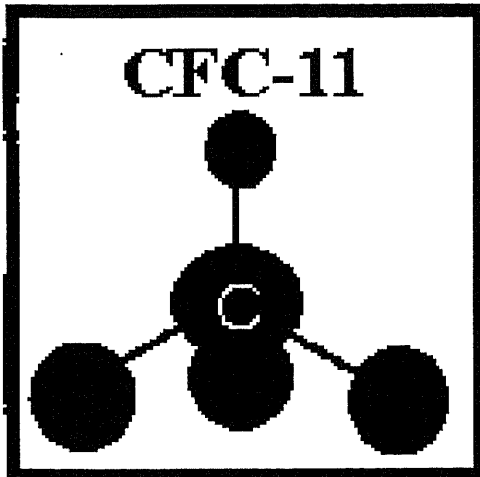
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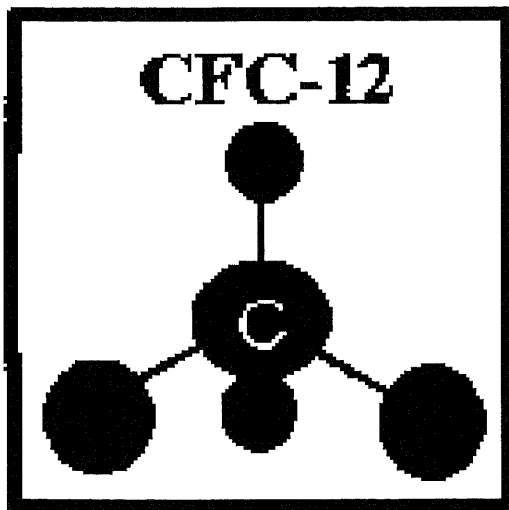
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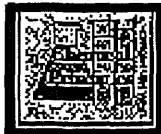
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## Stratospheric Ozone Layer Depletion



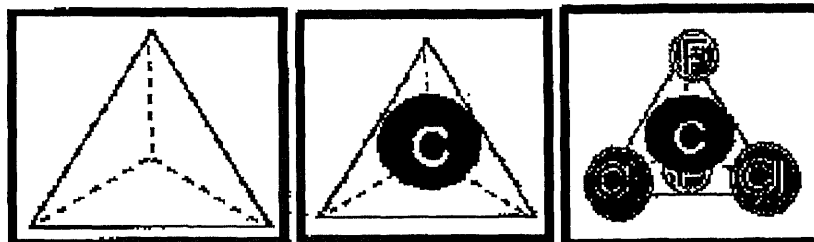
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### Characteristics of Freons

In general, all Freons are carbon compounds containing chlorine, fluorine. The most common Freon compounds are chlorofluorocarbons or CFCs in particular (CFC-12) whose chemical formula is  $CCl_2F_2$ . Freons are used so widely because of their high densities, low boiling points, low viscosity, and low surface energy, which are easily liquefied making them ideal for use as refrigerants and solvent. Freons made Freons a best seller amongst many industries. Also, the properties of Freons in many other areas. Freons are widely used as solvents, propellants, fire extinguishers, and other agents.

Before looking any further into the spread of CFCs, it is important to understand why they are chemically useful. Since CFC-12 is the most widespread, it will serve as a model for the chemical usefulness of the entire class of chemicals, known as CFCs. The molecular formula for CFC-12 is  $CF_2Cl_2$ . The name of this compound is dichlorodifluoromethane. To imagine what this would look like in three dimensions, you can do so by envisioning a pyramid with a triangle as its base. Place the carbon atom at the center of the triangle with the chlorines and fluorines at the four points. This is known as a tetrahedral configuration.



Each halogen is fighting to draw one electron away from the central carbon atom. At the same time, the carbon holds the electrons in the covalent bonds so it does not lose them. Since fluorine and chlorine are aggressive elements, the bonds which are formed are very strong. This acts as a stabilizing agent giving even more stability to this molecule.

These strong covalent bonds and added chlorine stability make CFC-12 inert. This means it does not react with other molecules in its surroundings. Besides its chemical inertness, CFC-12 has many other chemical and physical properties that make it ideal for use in many industries. Its boiling point allowed it to be used as a refrigerant eliminating the danger of explosive toxicity that was associated with ammonia. Also, because it was inert and nontoxic, it was used to blow foam for formation of containers or insulation. These same properties made it ideal for use in medical inhalers and aerosol spray cans. Other applications also arose as the other CFCs were produced. The low costs of production coupled with their versatility and widespread use helped them to find their way into many industrial operations.



The same property of inertness which makes CFCs so useful in industry would one day prove to be what makes them so dangerous to the planet. Even as CFCs became more widely spread in industry, they were slowly being vented to the atmosphere. At the time this was not seen as bad practice because they were thought to be safe. Unfortunately, CFCs do not naturally biodegrade. As a result, they persist in the atmosphere. Through natural processes, they make their way up into the stratosphere where the real problem begins. From their inception until the mid seventies, however, CFCs were seen as safe, useful, and noncontroversial.

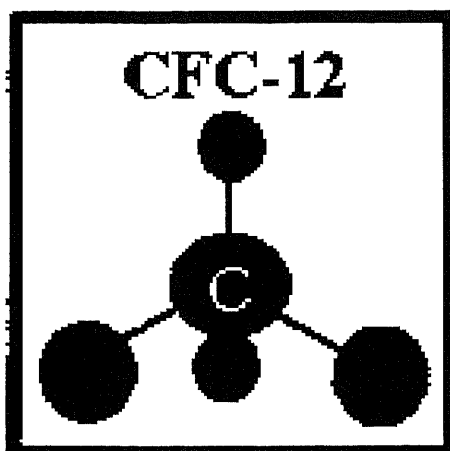
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### *The Spread of Chlorofluorocarbons*

With the introduction of CFC-11 and CFC-12, the air-conditioning and refrigeration industries began to boom. In 1932, the Carrier Corporation manufactured and marketed the first self-contained household air-conditioning unit, "the Atmospheric Cabinet." This brought the idea of comfort through technology and chemistry to the household consumer. It was not long before consumers devoured the new comforts brought by synthetic chemicals. Though consumer acceptance was slow at first, it eventually became an irresistible force.

Just before the beginning of the second World War, on September 8, 1941, Thomas Midgley Jr. received the American Chemical Society's Priestly award for outstanding creativity in the field of chemistry. His contributions to the field were extensive. CFCs are but one of his many innovations, all of which were designed to help humans live better and longer. In less than fifty years, however, this part of his work has come to be seen as something which could endanger the lives of all humans and perhaps, the planet Earth.

After the war, consumers demanded the many things that they had to do without during the times of rationing and conserving. Consumption was high, as were most people's hopes for the future. In 1956, America's first air-conditioned mall opened in Edina, Minnesota, ushering in the age of convenience and shopping pleasure. By 1958, 90% of the theaters, 40% of restaurants, and 25% of the hotel rooms in America were air-conditioned.

This idea of air-conditioned comfort was not confined to areas of entertainment. Between 1962 and 1966, 75% of all new apartments built were equipped with air-conditioning. Once the living environment had air-conditioning, American automobile air-conditioning soon followed. In 1963, 15% of the 6.5 cars in America had air-conditioning and only eight years later, in 1971, 58% of all American cars had air-conditioning, as did many truck cabs and other conveyances. By 1972, the living areas of America were being air-conditioned as well. More than half of all residences were equipped with some form of air-conditioning.

The spread of CFCs had not only made its way through American industry and the world, but these products had followed people everywhere. It had become possible for a person to remain within a few feet of air-conditioned space from the time they left their home in the morning until they returned at night. This one invention had become so commonplace that many could not imagine doing without it even for a short time. As with many other CFC related technologies, the usefulness and reliability of the technology made it very popular. CFCs did their job cheaply, efficiently, and well. For over forty years, no one thought there would ever be a problem with these wonder chemicals that had become a vital part of so many people's daily lives.

In December of 1973, two scientists made a discovery that would change the way the scientific community and the general public would view CFCs. F. Sherwood Rowland and Mario Molina had studied the effects of chlorofluorocarbons in the upper atmosphere and had concluded that these substances had the potential to deplete the ozone in the stratosphere. The significance of what they were claiming was so profound that they knew there would be a great deal of discussion

about their theory. In order to understand what the Rowland and Molina theory suggested, it is necessary to discuss some facts about the Earth's atmosphere and the molecules that are found there. In particular, ozone.

[More About Rowland and Molina](#)

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## ***More About Rowland and Molina***

In December of 1973, both Mario Molina and F. Sherwood Rowland were professors of chemistry at the University of California at Irvine. Molina had been at the school for only a few months while Rowland, his postdoctoral advisor had been there for several years. Molina approached Rowland with some calculations he had derived which indicated that CFCs which made their way into the upper atmosphere could break down and destroy the precious ozone layer. Rowland looked over the calculations and saw that Molina's work had potential to be correct. The two men worked together for two days examining the results of Molina's work. This one discovery would change the way scientists looked at CFCs and many other "harmless" chemicals.

At that time, worldwide production of CFCs was about 1 million tons per year. After studying the reactions that CFCs might participate in the troposphere, the two scientists realized that there was little chance that these highly unreactive chemicals would be removed from our atmosphere. As a result, they theorized that CFCs would slowly drift up to the stratosphere where ultraviolet light could cause them to release a chlorine molecule. This molecule was the key to the destruction of the ozone in the stratosphere. It would take many years for the two scientists to convince the scientific community that their theory was correct, but in the end, they succeeded.

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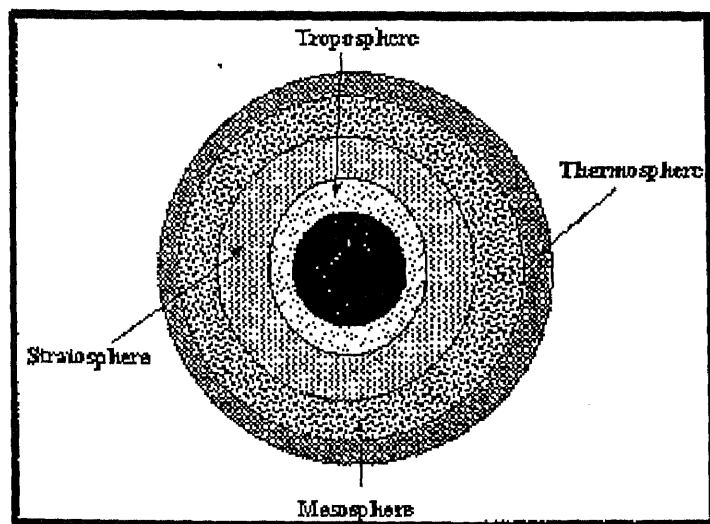
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### *The Earth's Atmosphere*

Before discussing the CFC problem, it is necessary to understand how the Earth's atmosphere is broken into layers. There are four distinct areas of air surrounding the Earth. Each has distinctive characteristics which change as the distance from the Earth's surface increases. The area humans live in is known as the troposphere. It begins at the surface of the earth and extends for 7-10 miles (11-16 km). The temperature and pressure decrease rapidly with altitude until the tropopause is reached. The tropopause is an area at which a temperature inversion occurs. This area acts as a nearly impervious barrier to most of the water trying to rise out of the atmosphere. This is important because what little water passes this point can escape into space.

Above the troposphere is the stratosphere which extends to a point approximately 31 miles (50 km) above the Earth's surface. Temperature remains fairly constant near the tropopause but begins to increase near the upper bound of the stratosphere as solar radiation increases. The water that passes the tropopause forms clouds here. The most important molecule in the stratosphere is ozone.

Next comes the mesosphere. It extends from the top of the stratosphere to an altitude of 50 miles (80 km). Finally, the top of the atmosphere is known as the thermosphere. It begins at 50 miles and continues to outer space. The temperature continues to increase through the mesosphere and the thermosphere.



Ozone is of concern to us when it is in the lower two levels of the atmosphere, the troposphere and the stratosphere. No matter where it is found, ozone is a relatively unstable molecule. An ozone molecule consists of three atoms of oxygen bound together in a triangular fashion. Although it

represents only a tiny fraction of the atmosphere, ozone is crucial for life on Earth.

Depending on where ozone is located, it can either protect or harm life on Earth. In the stratosphere, ozone acts as a shield to protect Earth's surface from the sun's harmful ultraviolet radiation. Without this shield, ultraviolet levels at the Earth's surface would be higher and humans would be more susceptible to skin cancer, cataracts, and impaired immune systems. In the troposphere, however, this same ozone molecule is a harmful pollutant that causes damage to lung tissue and to plants.

The amounts of helpful and harmful ozone in the atmosphere depend on a balance between processes that create it and those that destroy it. An upset in the ozone balance can have serious consequences for life on Earth. Scientists are finding evidence that changes are occurring in ozone levels. The harmful ozone is increasing in the air we breathe, while the helpful ozone is decreasing in our protective ozone shield. In the next few pages, the processes that create and destroy the helpful ozone will be described. Also, the way that humans effect these processes will be discussed.

At the top of the stratosphere ozone is created and destroyed primarily by ultraviolet radiation. The air in the stratosphere is bombarded continuously with radiation from the sun. The ultraviolet rays, which are part of this light, strike molecules of ordinary oxygen ( $O_2$ ) causing them to split into two single oxygen atoms, known as atomic oxygen or oxygen radicals. A freed oxygen atom then can collide with an oxygen molecule ( $O_2$ ), and form a molecule of ozone ( $O_3$ ).

This process absorbs much of the ultraviolet radiation which would otherwise reach the Earth's surface. Ironically, this same ultraviolet radiation also causes the destruction of ozone. When an ozone molecule ( $O_3$ ) absorbs even low energy ultraviolet radiation, it splits into an ordinary oxygen molecule ( $O_2$ ) and a free oxygen atom ( $O$ ). The free oxygen atom then may bond with an oxygen molecule to make another ozone molecule, or it may steal an oxygen atom from an ozone molecule to make two ordinary oxygen molecules. Some scientists call these processes of ozone production and destruction, initiated by ultraviolet radiation, the "Chapman Cycle."

#### See the Chapman Cycle

Natural forces other than the Chapman Reactions also affect the concentration of ozone in the stratosphere. Since ozone is such a highly unstable molecule, it reacts very easily, readily donating an oxygen molecule to nitrogen, hydrogen, or chlorine found in natural compounds. These elements always have existed in the stratosphere, released from sources such as soil, water vapor, and the oceans.

In addition, ozone levels can change periodically as part of regular natural cycles such as the changing seasons, sun cycles and winds. Moreover, volcanic eruptions may inject materials into the stratosphere that can destroy ozone.

Over the Earth's lifetime, natural processes have regulated the balance of ozone in the stratosphere. An easy way to think about the ozone balance is to imagine a plastic bag being filled with water. As the bag fills, a hole is punched in it to allow water to escape. As long as water escapes at the same rate that water is being poured in, the amount of water in the bag will remain the same. Likewise, as long as ozone is being created and destroyed at the same rate, the total amount of ozone will remain the same.

#### *Human Activity and the Atmosphere*

In the past two decades, however, scientists have found evidence that human activities are disrupting the ozone balance. Human production of chlorine-containing chemicals such as chlorofluorocarbons (CFCs) has added an additional force that destroys ozone. (CFCs are compounds composed of carbon atoms bonded to chlorine, fluorine.) As was seen earlier, CFCs are stable and thus do not react easily with other chemicals in the lower atmosphere. One of the few forces that can break apart CFC molecules is ultraviolet radiation in a process called

photochemical decomposition. In the lower atmosphere, however, CFCs are protected from this radiation by the ozone layer. So, CFC molecules can migrate intact into the stratosphere where they then are photodecomposed. At first, scientists thought CFCs were too heavy to make their way into the upper atmosphere. Although the CFC molecules are heavier than air, the mixing processes of the atmosphere lift them into the stratosphere. The mixing process takes many years, up to fifty, and so the problem is not easily noticed. The ozone in the stratosphere today is being destroyed by CFCs released many years ago.

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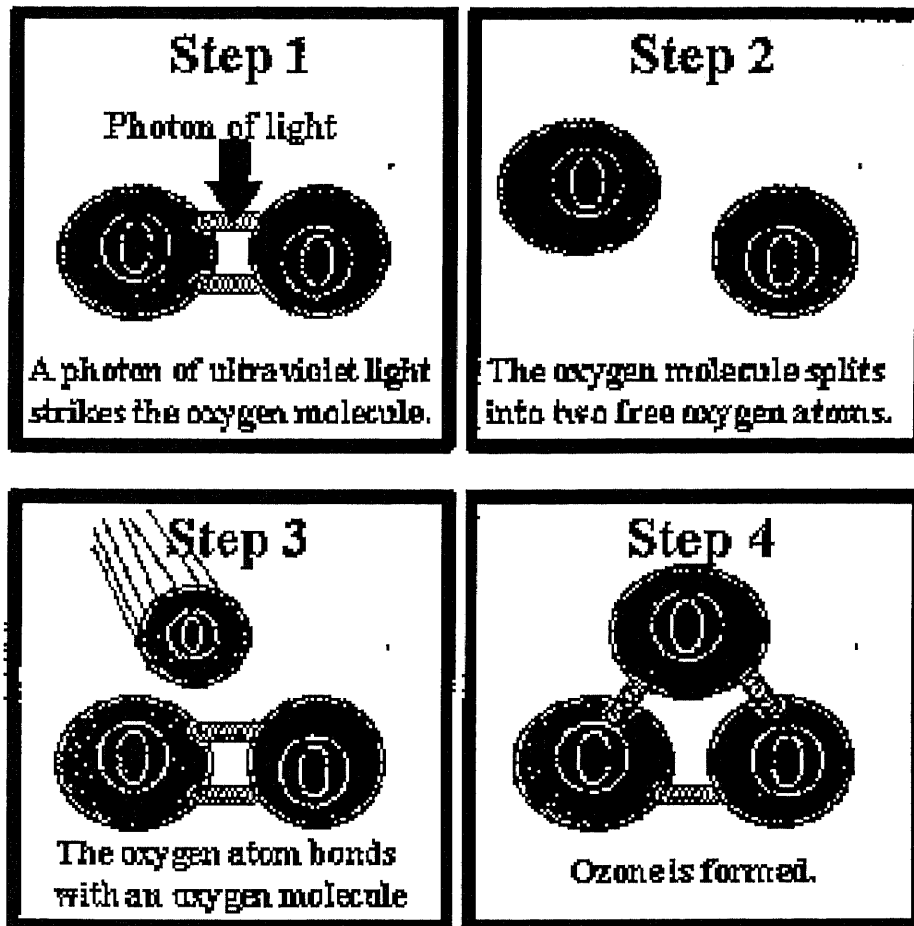


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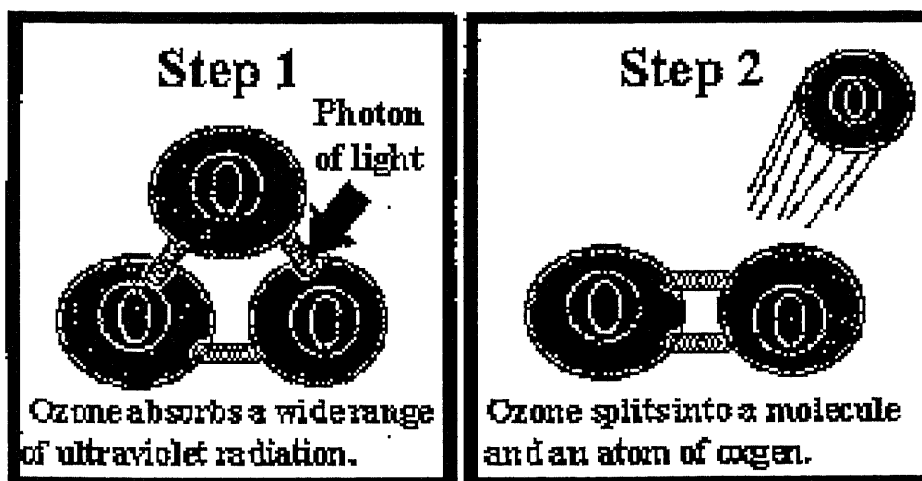


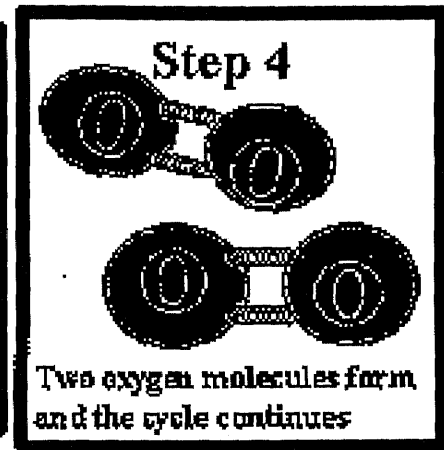
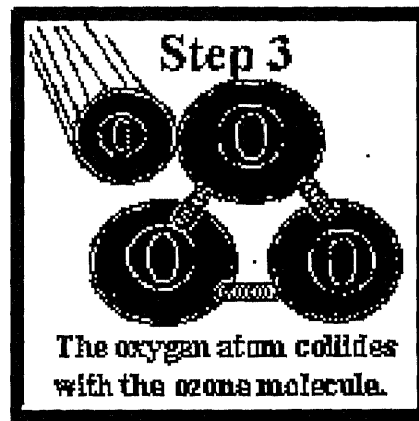
# The Chapman Reaction

## The Formation of Ozone



## The Destruction of Ozone





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### *The Destruction of Ozone*

There are many ways that ozone can be destroyed. As was shown in the Chapman cycle, ozone is transformed into a molecule and an atom of oxygen by ultraviolet light. However, this is not the only way that destruction of ozone occurs. When molecules of other elements make their way into the stratosphere, they can interact with the highly reactive molecule of ozone to destroy it. Many of these act as catalysts thus accelerating the destruction of ozone by their presence. A catalyst is a chemical which participates in a reaction without being consumed in the reaction itself. Catalysts increase the speed of reactions or reduce the amount of energy required to allow the reaction to occur. In the case of ozone destruction, atoms of hydrogen, nitrogen, or other elements can act as catalysts.

### More About the Ozone Catalysts

One of the most effective and thus dangerous catalyst is chlorine. Chlorine is released by CFCs when they reach the stratosphere. Once in the stratosphere, CFC molecules no longer are shielded from ultraviolet radiation by the ozone layer. Once exposed to the sun's radiation, CFC molecules release a chlorine atom or free radical. The chlorine then can react with ozone molecules, taking one oxygen atom to form chlorine monoxide and leaving an ordinary oxygen molecule behind.

### See the Rowland/Molina Reaction Pathway

If each chlorine atom released from a CFC molecule destroyed only one ozone molecule, CFCs probably would pose very little threat to the ozone layers. However, when a chlorine monoxide molecule encounters a free atom of oxygen, the oxygen atom bonds with the chlorine monoxide, forcing it to release the oxygen atom. As a result, the chlorine atom is released back into the stratosphere where it can attack another ozone molecule. This same reaction is repeated thousands of times in the stratosphere before the chlorine bonds to an other atom which will not release it back into the atmosphere.

Fortunately, chlorine atoms do leave the atmosphere or there would be no ozone left. When a free chlorine atom reacts with gases such as methane ( $\text{CH}_4$ ), it is bound up into a molecule of hydrogen chloride ( $\text{HCl}$ ), which can be carried from the stratosphere into the troposphere, where it can be washed away by rain. This removal process is important because it means that if humans stop adding compounds to the stratosphere, eventually, they will wash themselves out and everything will return to normal.

The reaction pathway by which CFC molecules are photodecomposed and work to destroy stratospheric ozone was first theorized by Rowland and Molina. After many years of presentations, papers, disputes, discussions, and debates, the theory was accepted. By that time, a great deal of evidence had been gathered to support the Rowland and Molina theory as well as show that there was indeed a hole in the ozone layer above the continent of Antarctica.

### *The Ozone Hole*

In the area over Antarctica, clouds hold ice particles that are not present at warmer latitudes. Reactions occur on the surface of the ice particles that accelerate the ozone destruction caused by stratospheric chlorine. This phenomenon has caused documented decreases in ozone concentrations over Antarctica. In fact, ozone levels drop so low in spring in the southern hemisphere that scientists have observed what they call a "hole" in the ozone layer. At first this was not that horrifying a discovery because there were no people living on the continent. Unfortunately, the conditions worsened and spread. Also, at the end of spring, the hole lost its integrity and shifted to more populated areas such as Australia and southern Chile. Scientists began to see a global dilution of ozone as more and more ozone was destroyed in the ozone hole.

In addition, scientists have observed declining concentrations of ozone over the whole globe. In the second half of 1992, for example, world-wide ozone levels were the lowest ever recorded.

Since the 1920's, ozone has been measured from the ground. Scientists place instruments at locations around the globe to measure the amount of ultraviolet radiation getting through the atmosphere at each site. From these measurements, they calculate the concentration of ozone in the atmosphere above that location. These data, although useful in learning about ozone, are not able to provide an adequate picture of global ozone concentrations.

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## Ozone Destruction Catalysts

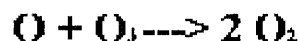
Though most of the water which evaporates from the surface of the Earth returns as precipitation, some does escape the troposphere. The concentration of water in the stratosphere is approximately 5 parts per million. Though small, this is still significant because of the way the water reacts with atomic oxygen and ozone. Once in the stratosphere, ultraviolet radiation causes the water molecule, chemical formula  $H_2O$ , to break down into two parts,  $H$  and  $OH$ . These two parts individually react in the stratosphere to break down ozone in the following manner.



When these two equations are added together, you get:



Crossing out the terms which appear on both sides gives:



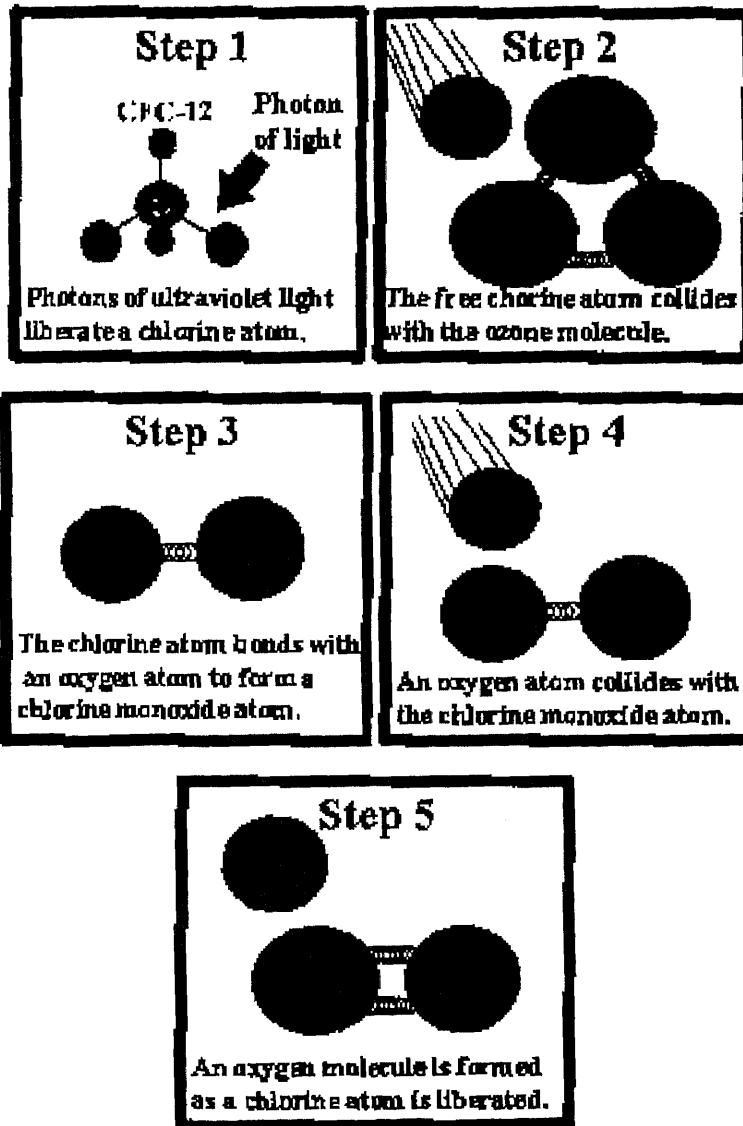
In this way, the water is still present at the end of the reaction and is available to continue the cycle. It has participated in the reaction without being consumed and thus is a catalyst. This is a natural process which is necessary to maintain the balance of ozone in the stratosphere. Trouble arises however, when other molecules which do not normally occur in the stratosphere or which are usually found in lower concentration make their way into the stratosphere due to human activity. Chlorine is one of these chemicals.

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## The Rowland/Molina Reaction Pathway

The process by which chlorine is liberated from a Chlorofluorocarbon by ultraviolet radiation and then works to destroy ozone is shown below. The key to this cycle is that chlorine is a catalyst and so is not consumed in the reactions shown.



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### *The Role of Science*

Contrary to the image created by the term "ozone layer," the amount and distribution of ozone molecules in the stratosphere vary greatly over the globe. Ozone molecules drift and swirl around the stratosphere in changing concentrations. Therefore, scientists observing ozone fluctuations over just one spot could not be confident that a change in local ozone levels meant an alteration in global ozone levels, or simply a fluctuation in the concentration over that particular spot.

In December of 1974 the first government hearings in the United States were held on the CFC-ozone theory. These hearing were the opening volley in a war over CFCs in the United States and around the globe. Many governmental and non-governmental agencies worked to find answers to the questions raised by the Rowland and Molina theory. Once enough scientists agreed to the idea that CFCs could deplete stratospheric ozone, these groups began working to ban CFCs.

Many companies saw that CFCs were dangerous and not essential to their product lines. These companies voluntarily banned CFCs. Both state and federal governments moved to give the CFC ban the force of law in the following years.

Even so, there was still debate over the extent to which CFCs actually destroyed the ozone layer. In August, 1981 NASA scientist Donald Heath announced that satellite records showed ozone over the earth had declined 1 percent. From that point on, there was little question that there was a problem and that something needed to be done about it. Unfortunately, the political process did not act swiftly enough for some and moved too quickly for others. Though the scientific facts had been debated for over ten years, there was still no clear plan of action.

Satellites had given scientists the ability to overcome the problem of uncertainty because they provide a picture of what is happening simultaneously over the entire Earth. However, the speed of ozone depletion was still debated and only slowly was the seriousness of the ozone depletion problem realized. Even the ozone hole did not seem to give enough force to the arguments for banning CFCs. Many different theories were postulated to explain the problem. In the end, CFCs were blamed and the global consensus began to build behind the idea that CFCs should be banned. Scientists had finally conceded that though there were natural forces at work which could deplete ozone, human interference in the natural cycles had accelerated the process of ozone destruction. Without some type of action, the ozone layer would continue to deteriorate until it was no longer able to protect the surface of the Earth from ultraviolet radiation.

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### *Banning CFCs*

As little as one year after Rowland and Molina announced their theory publicly, government agencies and private corporations began responding. Johnson Wax, America's fifth largest producer of aerosol spray can, announced that they would stop production. At that same time, Oregon bans the use of CFC containing aerosols. Soon the United States government follows suit and by October of 1978, aerosol spray cans were banned in the United States. Unfortunately, most other consumers and the largest producer of CFCs, DuPont, refuse to admit there is a problem. Slowly, more and more evidence is found to support the Rowland and Molina theory. By 1987, the United States government has decided that stricter regulations are needed in many areas. Other manufacturers have voluntarily agreed to phase out CFCs ahead of EPA mandated phase-out schedules. Almost fifteen years after Rowland and Molina first suspected that CFCs could cause the depletion of the stratospheric ozone layer, the world community of scientists and policy-makers were about to come together to formulate a comprehensive policy to do something about the problem.

### *The Montreal Protocol*

If scientists can separate the human and natural causes of ozone depletion, they can formulate improved models for predicting ozone levels. The predictions of early models already have been used by policy makers to determine what can be done to reduce the ozone depletion caused by humans. For example, faced with the strong possibility that CFCs could cause serious damage to the ozone layer, policy makers from around the world signed a treaty known as the Montreal Protocol in 1987. The signatory countries agreed to reduce production of CFCs by 50% from the 1986 baseline values by 1996. In order to achieve this goal, the protocol set out different phase-out schedules for allowable and accelerated phase-outs. These two plans were at opposite ends of the spectrum. Accelerated refers to the fastest possible removal while allowable is the removal at the last possible moment.

The protocol also made some concessions to less developed countries (LDCs). These concessions included a ten year grace period before compliance was required as well as a recommendation to the more developed countries to help pay for the transition to CFC alternatives. Even though there was scientific consensus concerning the harmful nature of CFCs, the economic benefits provided by using the chemical provided a formidable problem which needed to be overcome. LDCs could not or would not forgo their use without some attractive economic incentives. This interplay between the facts that science promotes and the economics which drives society, is the balancing act that policy-makers must try to control. Though the original protocol was not perfect, it was a good attempt at trying to balance international environmental concerns about the depletion of the ozone layer and the economic concerns of many of the LDCs who would have to comply with its cuts.

The initial ratifiers of the protocol included Canada, Denmark, Egypt, Finland, France, West Germany, Ireland, Italy, Japan, Malta, Mexico, The Netherlands, New Zealand, Norway, Spain, Sweden, The United Kingdom, The United States and The USSR. The protocol went into effect on



January 1, 1989 after these countries ratified it. Table 1 shows the major emitters of CFCs at that time.

TABLE 1—Major Emission of CFCs in 1989

COUNTRY	RANK	CFC EMISSION (1000 METRIC TONS)	PERCENT OF WORLD TOTAL
U.S.	1	138	22.4
JAPAN	2	96	16.4
USSR	3	67	11.6
GERMANY	4	34	6.7
UK	5	26	4.3
ITALY	6	25	4.3
FRANCE	7	24	4.1
SPAIN	8	17	2.9
CHINA	9	12	2.1
CANADA	10	11	1.9
AUSTRALIA	11	8	1.4
S. AFRICA	12	7	1.2
TOTAL		485	78.4
WORLD		580	100

This table shows the unbalanced contribution to the problems by members of the world community. The top twelve emitters contribute 78.4% of the world total of CFCs. Worse than that, the top three emitters—the U.S., Japan, and the USSR—contributed a combined 292,000 metric tons of the world's total of 580,000 metric tons of CFC pollution. These three nations emit 50.4% of the CFCs in the world's atmosphere. Facts such as these, coupled with continuing pressure from world governments and nongovernment organizations, allowed amendments to the original Montreal Protocol to be developed.

Though the 1987 Montreal Protocol was a good beginning, more evidence of rapidly increasing ozone depletion over both poles led to a rising tide of concern and a movement for accelerated phase-out of CFCs. In 1990, the London Amendments were passed. The signatory countries for these new amendments agreed to a total ban of CFCs by the original 1996 date. Also, they established a relief fund for LDCs that would be adversely affected by the new agreement. The original protocol did not attract China or India—two major potential users. After the amendments, however, these and many other countries participated in the ban with the understanding that the fund of \$260 million dollars would be used to offset their costs. Two year later, the Copenhagen Amendments increased the fund to over \$500 million and accelerated the compliance schedule. These adjustments have made the Montreal Protocol an effective international agreement that has succeeded in gathering support from the nations of the world.

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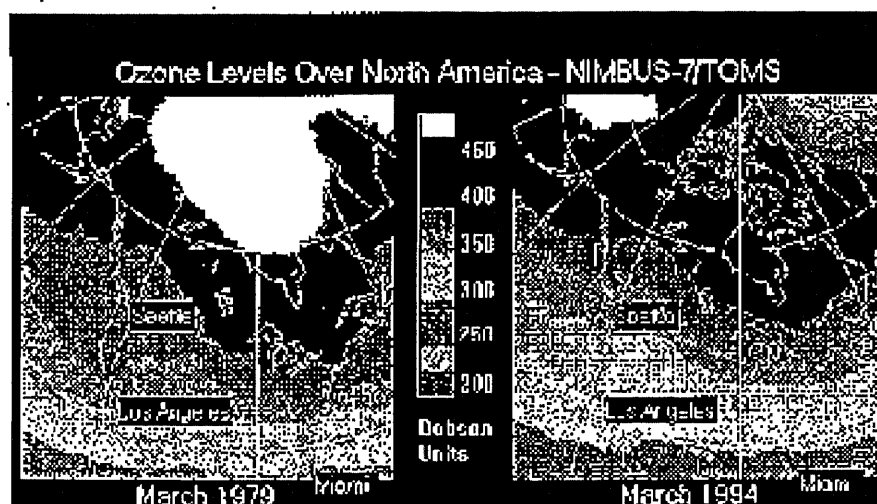
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### *Monitoring Ozone From Space*

However, scientists agree that much remains to be learned about the interactions that affect ozone. To create accurate models, scientists must study simultaneously all of the factors affecting ozone creation and destruction. Moreover, they must study these factors from space continuously, over many years, and over the entire globe. NASA's Earth Observing System (EOS) will allow scientists to study ozone in just this way. The EOS series of satellites will carry a sophisticated group of instruments that will measure the interactions of the atmosphere. These measurements will increase dramatically our knowledge of the chemistry and dynamics of the upper atmosphere and our understanding of how human activities are affecting Earth's protective ozone layer.

A graphic example of what satellites can reveal is shown below.



Source: NASA, Goddard Space Flight Center

This figure shows the difference in the thickness of the ozone layer over North America between 1979 and 1994. By looking closely at the colors on the graph, the loss of ozone over North America can be seen quite clearly. Most noticeably, the large white portion of highest ozone concentration has receded away from the areas of America which release CFCs.

A dramatic example such as this makes the problem very clear. In only fifteen years, the ozone layer has been degraded significantly. Luckily, something has been done about it.

In response to the Montreal Protocol and public pressure resulting from the findings of scientists, governments around the world began passing legislation which restricted or banned the use of

CFCs. The United States was no different. Individual state legislatures as well as the Congress passed laws banning CFCs. These laws grew more stringent and broadened to encompass more products as time passed. By the 1990's, CFCs had been banned in the United States with only slight exceptions for medical and other highly specialized uses. Even with these types of regulations, it was important that the corporations of the world agreed to the Montreal Protocol and other regulations.

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### *Alternatives*

An important step forward in the struggle to remove CFCs from the atmosphere was fought on the economic front. Just as the economic attractiveness of CFCs made them spread so quickly through industry, consumer concerns and eventual disuse of the product helped remove them from many areas. In 1990, DuPont Chemical company, the largest producer of CFCs, agreed to a two-phase removal plan in which substitutes would be developed and then slowly phased into the existing industrial system. This corporate backing of the CFC removal program helped immeasurably. Many other companies worked to reduce the use and release of CFCs in their industrial and corporate facilities around the world. Also, many entrepreneurs have used the idea of ozone-safe products to further their business and increase profits. As consumers became aware of the problems and understood what they could do to help, business and industry has worked harder to solve the problem and find a better way of conducting their operations.

DuPont's answer to the problem of CFCs was to develop less chlorinated fluorocarbons that would impact the ozone layer less severely. They began by introducing hydrochlorofluorocarbons (HCFCs). These were CFCs with chlorine partially replaced by hydrogen molecules. As an interim measure these chemicals proved very useful. They began the phase-out of CFCs without too great a capital cost to industry and without causing too great of an inconvenience to consumers. HCFCs were not as damaging to the stratospheric ozone layer but were not completely safe. Tests showed that they could still break down and deplete the precious ozone. As a more permanent replacement, DuPont announced that it had developed a line of hydrofluorocarbons (HFCs) which contained no chlorine and thus posed a greatly reduced threat to the ozone layer.

Along with the work by DuPont, several other alternatives have been suggested. Cyclopentane and cyclohexane have been put forth as replacements for coolants. Nitrogen gas can be used as a blowing agent. Many other safe and easily obtainable alternatives exist and have been used successfully for years. CFCs in aerosol cans have been replaced with air pressure or other propellants. With a little effort, it seems that CFCs have been replaced without a tremendous furor as was expected when the idea of their replacement first came to the table for discussion.

Though the strides made by DuPont and the other scientists working to provide alternatives to CFCs are significantly reducing the quantity of CFCs being released, more can be done. Companies have seen that reducing the use of CFCs is an effective way of stopping their release without waiting for replacements. AT&T, for example has worked to prevent the release of CFCs by auditing their facilities and finding ways to cut back on their consumption of the chemicals. Other companies have found that manufacturing CFC-free products has become very lucrative. Whirlpool has recently opened a plant to manufacture CFC-free refrigerators in India. Other companies have begun selling environmentally safe products to consumers. In 1995, Walmart opened the first entirely environmentally safe shopping area in the world. These types of innovations and forethought will be necessary to stop the depletion of the stratospheric ozone layer along with many of our other environmental problems. Cooperation between scientists, politicians, economist and many others will be vital to the continued success of the world as a

whole. Global problems must have global solutions reached through global consensus and understanding.

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# GOTO:

## Ozone Case Study Main Menu

### Timeline

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### Title Page

### **5.1.3 The Significant Revisions Explained**

Other than cosmetic changes such as spelling errors and awkward sentences, there were several changes to the content and presentation of the text of the tool. These changes will be noted by page as they appear in the new version of the tool which appears above.

There were two types of changes made to the tool. In order to make the tool more complete and technically correct, editing changes were made to all the pages of the text. Some of the pages needed more significant changes such as the addition of examples, graphics, or links to subpages containing additional information. Pages two, four, seven, eight, fourteen, fifteen, sixteen, and seventeen had only textual changes. The remainder of the pages in the tool had more significant changes made to them. These changes are listed below.

Beginning with the case study selection page, it has been decided that the overall tool in which the stratospheric ozone layer depletion case study will be placed will only have two other case studies. This will allow more information to be included in the ozone case study.

Next comes the ozone case study main menu. The additions to this page are both in content and presentation. The order in which information is given to the user has changed. The introduction at the top of the page has been made more comprehensive. A brief explanation of some of the features of the tool have been included on this page to make it quicker and easier for students to use. For example, the Goto button on the bottom of the page has been explained in text above the button. Finally, the note about the tutorial has been move to the bottom of the page.

The most significant changes appear on the next group of pages. What was formally the Historical Overview/Timeline has now become “The Overview & Timeline” (overview). A brief explanatory paragraph now appears at the top of the first page of the overview. Underneath this explanation appears a table of contents which links the student to each page of the tool. Each section of the overview corresponds to a page in the narrative of the tool. Each section has at least two links and one icon. The icon gives the student an idea of the major field covered on that page as well as a graphical link to help them remember what they are studying. Along with the icon, each section has the appropriate page number listed. By clicking this number, the student is brought to the top of that page. A link to a summary about the page is also included in each section. Though none of the experts specifically suggested that a summary be added, a short synopsis about each page of the narrative seemed to be necessary to eliminate the confusion that might occur as a student tries to work through the overview.

Two additional links can appear in a section. First, important dates that appear on a page may appear in the overview. These dates link the student directly to that portion of the narrative. The other type of link which appears is a link to a page containing other important dates which relate to the material being discussed on a particular page. This page can be accessed by clicking the “Additional Dates of Interest” button. These dates are the same ones which appeared in the original timeline as nonclickable entries. Since some experts felt that these dates were important while other wanted them to be paired down, putting them on a subpage seemed to be the best solution. Overall, the changes to this page make it much easier to understand and follow.



Besides simple format changes to the formulas on page one, there are three major revisions or additions. The first revision is the second paragraph on this page which was added at the request of Mr. Wallace. He felt that an introduction to the goal of the case study would help the student better understand how the material which was going to be presented fit together. The other two revisions consist of two links which were added to this page. The first, "What is a Mole," links the student to a definition of a mole which is necessary to understand the gas laws as well as other chemistry concepts. The second link, "An Example of Boyle's Law," is a very rudimentary example of the law.

Two links were added to page three. The first is an example of Charles' Law titled, "An Example of Charles' Law". The second gives more information about ideal gasses to help the student understand the applicability of the ideal gas law. This link is titled, "More about Ideal Gasses."

The same link, titled "See the Periodic Table," was added to page five and page six. A copy of the periodic table which appears on page four was added to each page.

The addition to page nine consists of both links and graphics. Both the links and graphics are molecular models used to help the students as they try to visualize the molecules being discussed. Pictures of CFC-11 and CFC-12 were placed on separate pages to allow the student to work through the body of the text with less delays. If the picture is necessary it can be accessed but otherwise, transfer time can be saved.

Page ten has a graphics addition to show the student the three dimensional configuration of the molecules in question.

Page eleven has a link, titled “More about Rowland and Molina,” added to give the student more about these two scientists.

There is one link titled “See the Chapman Cycle,” added to page twelve. The accompanying subpage is a combination of both graphic and textual explanation of the Chapman cycle. The experts felt that this was necessary to show the students what was happening.

Finally, on page thirteen, there are two links. The first, titled “More About Ozone Catalysts” leads to an explanation of catalysts, as well as an example of a catalyzed reaction in the stratosphere which destroys ozone naturally. The second link, titled “See the Rowland/Molina Reaction Pathway,” connects to a description of the reaction pathway. As with the Chapman cycle, both a graphical and textual explanation of the reaction pathway is described. For the same reasons as above, this type of presentation was chosen for the material.

## **5.2 Closing Remarks**

The tool is the first step in a new approach to education. It tries to look at a global problem from a range of disciplines. Moreover, it brings together several disciplines whichever traditionally worked on similar problems separately to come to different solutions. If the tool can be shown to be effective, the way problems are approached can be changed. A new generation of workers can begin to look at the problems which they face from an interdisciplinary view rather than just from the narrow discipline in which they are trained. No longer will we educate students to just be chemists, engineers, historians, economists or any of a thousand different disciplines. Instead, the educational

system will produce well-rounded balanced problem solvers who can attack any problem and be comfortable looking at all the facets in order to come to a solution that addresses all the problems.

At the same time, this new generation of student will be comfortable working with a collection of experts from various fields. Expert knowledge about problems will be seen as a resource to be tapped by this new breed of problems solvers rather than a way to pass the problem along. If the attitudes of the students can be changed through the process of reeducation, many things can be accomplished. This tool is the first step in a new wave of problem solving. Starting to show the interconnectedness of the many disciplines which traditionally have been separated is an important first step to reaching a higher level of problem-solving.

As was stated in the first chapter of this thesis, global problems need global solutions. Global problems also need global problem-solvers. It will be impossible to find global problem solvers unless someone starts training them now before the environmental problems of the world become so great that it is too late to start.

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