The following contains excepts from the books:

1. “Essential Biology” Campbell, Reece & Simon, ISBN 978-0805368420
2. “Biology, A Guide to the Natural World” Krogh, ISBN: 978-0131414495

<u>Compiled for week 1 material of NS 102</u>

Human Impact on the Atmosphere and Climate

We are causing radical changes in the composition of the atmosphere and, consequently, in the global climate. Our activities release a variety of gaseous waste products. We once thought that the vastness of the atmosphere could absorb these materials without significant consequences, but an astronaut's view of our little planet squashes such naive notions **(Figure 20.9)**. One pressing problem that relates directly to one of the chemical cycles we examined is the rising level of carbon dioxide in the atmosphere.

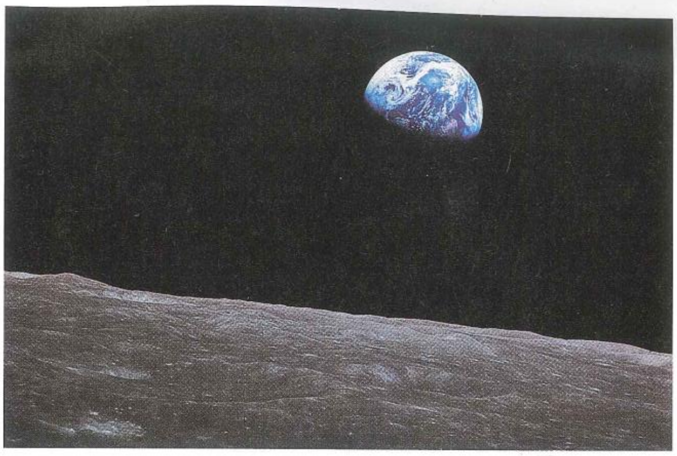


Figure 20.9 An earthrise photographed from the moon. Apollo astronaut Rusty Schweickart, reflecting on such a view, once remarked: "On that small blue-and-white planet below is everything that means anything to you. National boundaries and human artifacts no longer seem real. Only the biosphere, whole and home of life."

Carbon Dioxide Emissions, the Greenhouse Effect, and Global Warming Since the Industrial Revolution, the concentration of CO_2 in the atmosphere has been increasing as a result of the combustion of fossil fuels and the burning of enormous quantities of wood removed by deforestation. Various methods have estimated that the average CO_2 concentration in the atmosphere before 1850 was about 274 parts per million (ppm). When a monitoring station on Hawaii's Mauna Loa peak began making very accurate measurements in 1958, the CO_2 concentration was 316 ppm **(Figure 20.10)**. Today, the concentration of CO_2 in the atmosphere exceeds 370 ppm, an increase of about 17% since the measurements began just over 45 years ago. If CO_2 emissions continue to increase at the present rate, by the year 2075 the atmospheric concentration of this gas will be double what it was at the start of the Industrial Revolution. It is difficult to predict the multiple ways this intrusion in the carbon cycle will affect the biosphere and its various ecosystems.

One factor that complicates predictions about the long-term effects of rising atmospheric CO_2 concentration is its possible influence on Earth's heat budget. Much of the solar radiation that strikes the planet is reflected back into space. Although CO_2 and water vapor in the atmosphere are transparent to visible light, they intercept and absorb much of the reflected heat radiation, bouncing it back toward Earth. This process, called the

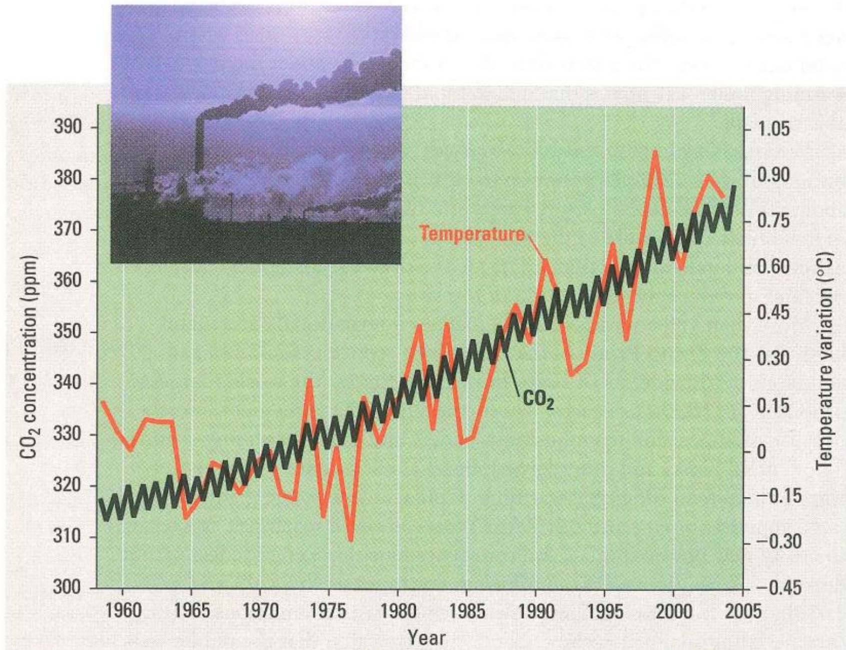


Figure 20.10 Increase in atmospheric CO_2 and temperature variation since 1958. The data were collected at Mauna Loa, Hawaii. The burning of fossil fuels (photo) was the main contributor to the increases observed.

greenhouse effect, retains some of the solar heat. **Figure 20.11** adds some details to the illustration of the greenhouse effect you saw in Figure 7.18.

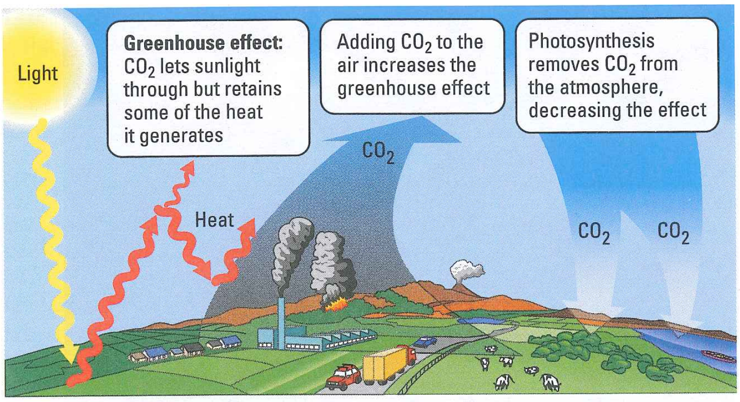


Figure 20.11 Factors influencing the greenhouse effect.

The marked increase in atmospheric CO_2 concentrations during the last 150 years concerns ecologists because of its potential effect on global temperature through the greenhouse effect. The black line in Figure 20.10 plots the warming trend during the period of increasing CO_2 concentration. A number of studies predict that a doubling of CO_2 concentration by the end of the 21st century will cause an average global temperature increase of about 2°C. Such an increase would make the world warmer than at any time in the past 100,000 years. A worst-case scenario suggests that the warming would be greatest near the poles. Melting of polar ice might raise sea level by an estimated 100 m, gradually flooding areas 150 km (or more) inland from the current coastline. New York, Miami, Los Angeles, and many other cities would then be underwater. A warming trend would also alter the geographic distribution of precipitation, making major agricultural areas of the central United States much drier. Most of Earth's natural ecosystems would also be affected, with boundaries between systems such as forests and grasslands shifting. However, the various mathematical models that have been used to study this question disagree about the details of how warming on a global level will change the climate in each region.

By studying how prehistoric periods of global warming and cooling affected plant communities, ecologists are using another strategy to help predict the consequences of future temperature changes. Records from fossilized pollen provide evidence that plant communities are altered dramatically by climate change. However, past climate changes occurred gradually, and plant and animal populations could spread into areas where conditions allowed them to survive. A major concern about the global warming under way now is that it is so rapid that many species may not be able to adapt.

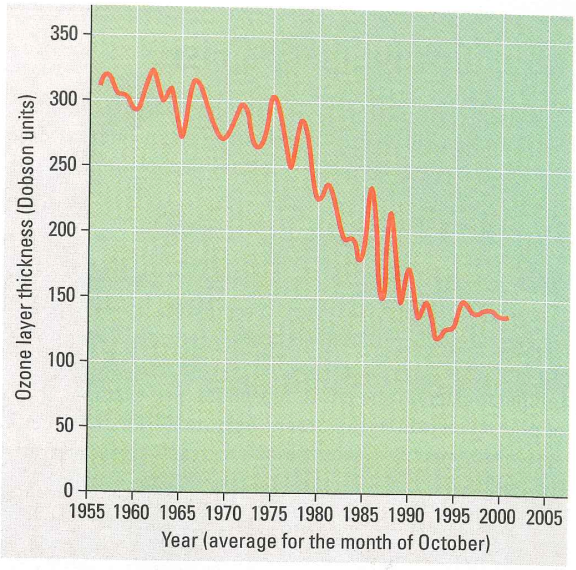
What can be done to lessen the chances of greenhouse disaster? The burning of trees after deforestation to clear land in the tropics accounts for about 20% of the excess CO_2 released into the atmosphere. The burning of fossil fuels is the cause of the other 80%. International cooperation and national and individual action are needed to decrease fossil fuel consumption and to reduce the destruction of forests.

More than 189 countries have signed an international agreement known as the Kyoto Protocol that intends to reduce greenhouse gas emissions worldwide. As of 2006, the United States, the world's largest producer of greenhouse gases, had not accepted the agreement, mostly because of opposition from business leaders and global-warming skeptics. The United States and other large industrial nations are searching for ways to help fend off global warming. China, an economic giant with a huge appetite for cars and other fossil fuel–powered machines, is working to create new power sources and transit systems that generate less carbon dioxide. A few automakers are offering new types of "hybrid" gas/electric cars that use less fossil fuel and release fewer harmful emissions. These cars are being snapped up by U.S. consumers, a sign that the public welcomes a shift away from fossil fuels, but so far their share of the U.S. auto market is quite small. Another "green technology"—solar systems for heating water and generating electricity—is becoming an increasingly popular option for homes.

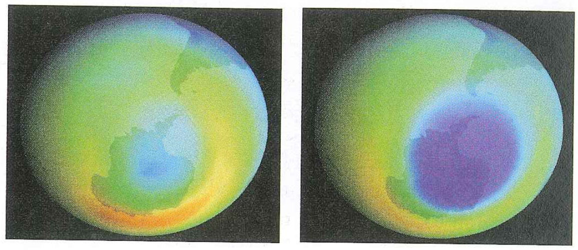
Depletion of Atmospheric Ozone Life on Earth is protected from the damaging effects of ultraviolet (UV) radiation (see Chapter 10) by a very thin protective layer of ozone molecules (O_3) located in the atmosphere between 17 and 25 km above Earth's surface. This **ozone layer** absorbs UV radiation, preventing much of it from reaching organisms in the biosphere. Measurements by atmospheric scientists document that the ozone layer has been gradually thinning since the middle of the 20th century **(Figure 20.12)**.

The destruction of atmospheric ozone probably results mainly from the accumulation of chlorofluorocarbons, chemicals used in refrigeration, as propellants in aerosol cans, and in certain manufacturing processes. When the breakdown products from these chemicals rise in the atmosphere, the chlorine they contain reacts with ozone, converting it to O_2. Subsequent chemical reactions liberate the chlorine, allowing it to react with other ozone molecules in a chain reaction. The effect is most apparent over Antarctica, where cold winter temperatures facilitate these atmospheric reactions. Scientists first described an "ozone hole" over Antarctica in 1985. Since then, the size of the ozone hole has increased (see Figure 20.12a), sometimes extending as far as the southernmost portions of Australia, New Zealand, and South America. And at the more heavily populated middle latitudes, ozone levels have decreased 2–10% during the past 20 years.

The consequences of ozone depletion may be quite severe for all life on Earth, including humans. Some scientists expect the growing intensity of UV radiation to increase the incidence of skin cancer and cataracts among humans. It is likely that there will also be damaging effects on crops and natural communities, especially the phytoplankton that are responsible for a large proportion of the biosphere's primary productivity. The danger posed by ozone depletion is so great that many nations agreed in 1987 to end the production of chlorofluorocarbons by the year 2010. (The United States and other industrialized nations have already substituted safer compounds for chlorofluorocarbons, but a grace period was allowed for developing countries.) As a result of such action, ozone depletion has slowed. Unfortunately, even if all chlorofluorocarbons were banned today, the chlorine molecules already in the atmosphere will continue to degrade atmospheric ozone for at least a century. It is just one more example of how far our technological tentacles reach in disrupting the dynamics of ecosystems and the entire biosphere.



(a) Thickness of ozone layer



1979 **2000**

(b) Ozone hole

Figure 20.12 Erosion of Earth's ozone shield. **(a)** This graph tracks the thickness of the ozone layer in units called Dobsons. **(b)** The ozone hole over Antarctica is visible as the blue patch in these images based on atmospheric data.

CHECKPOINT

1. How can clear-cutting a forest damage the water quality of nearby lakes?
2. How does the excessive addition of mineral nutrients to a lake eventually result in the loss of most fish in the lake?
3. How is biological magnification relevant to the health of most humans in developed countries?
4. From the data in Figure 20.10, what was the approximate percentage increase in atmospheric CO_2 between 1960 and 1990?

Answers: **1.** Without the growing trees to assimilate minerals from the soil, more of the minerals run off and end up polluting water resources. **2.** The eutrophication (overfertilization) initially causes population explosions of algae and the organisms that feed on them. The respiration of so much life, including the detritivores decomposing all the organic refuse, consumes most of the lake's oxygen, which the fish require. **3.** People in developed countries generally eat more meat than do people in developing countries. As secondary or tertiary consumers in a food chain, meat-eaters acquire a greater dose of certain toxic chemicals than if they fed exclusively on plants as primary consumers. **4.** About 12%, from 315 ppm to about 352 ppm; $352 - 315 = 37$, and $(37/315) \times 100 = 11.7\%$

The Worrisome Issue of Ozone Depletion

Given the importance of the ozone layer, it is sobering to contemplate how fragile it is. Some human-made chemical compounds have the effect of destroying stratospheric ozone, and such destruction went on unchecked for years until atmospheric chemists Sherwood Rowland and Mario Molina revealed, in 1974, that compounds called chlorofluorocarbons posed a direct threat to the ozone layer. Chlorofluorocarbons or **CFCs**—found at one time in spray cans, refrigerators, and plastic foams—are undoubtedly the most famous of the ozone-depleting compounds, but they are by no means the only chemicals that have this effect. Other harmful compounds include methyl bromide, which is used as a pesticide, notably on tomato and strawberry crops; and bromine, which is found in a group of fire-extinguishing chemicals.

The damage that these compounds have done to stratospheric ozone has brought about the spectacle of annual reports on how big the "ozone hole" is over the South Pole, along with a concern about a general thinning of the ozone layer. In 2000, the spring ozone hole grew to a record 11 million square miles—an area three times the size of the United States. So large was this hole that, for the first time, it extended over a center of human population, the city of Punta Arenas in southern Chile. The residents of this city thus joined life-forms in the Antarctic in being seasonally exposed to potentially harmful levels of ultraviolet radiation.

Despite the ominous nature of this news, the long-term outlook on ozone depletion actually is good. In an agreement signed in Montreal in 1987, many of the world's nations pledged to phase out production of ozone-depleting chemicals, and this agreement is working. Production of CFCs was banned in the United States even before the Montreal agreement was signed and has dropped dramatically throughout the world in recent years. Meanwhile, methyl bromide may be phased out in the United States by 2005, though this is not certain.

Critically, the reduction in the use of these compounds has brought about a reduction in the levels of ozone-depleting compounds in the atmosphere. As a consequence, while the ozone layer is still getting thinner, the *rate* of its thinning is slowing. Should this trend continue, it seems likely that the ozone layer will be restored, though this process may take decades.

The Worrisome Issue of Global Warming

A second environmental issue involving the atmosphere is that of global warming, which we've touched on a little already. The essential questions regarding this issue are straightforward: Is the Earth getting warmer? If so, to what degree is human activity responsible for this warming? And, if the Earth is warming, what consequences will this have? Put another way, what will a warmer Earth be like?

Is the Earth Getting Warmer?

At one time, all of these questions were contentious within the scientific community. In the last few years, however, near-unanimity seems to have been reached regarding one of them—*whether* the Earth is warming. Almost all parties are now agreed that Earth's surface temperature is indeed rising. It probably has increased by about 0.6° Celsius (or about a degree Fahrenheit) in the past century, with much of this increase coming in just the past 20 years. It's likely that, globally, the 1990s was the warmest decade since the middle of the nineteenth century. For the Northern Hemisphere, at least, the 1990s appear to have been the warmest decade in the last thousand years.

Is Human Activity Responsible?

This leads to the second question, which is whether human activity has caused this increase. Here, while there is still disagreement, a consensus seems to have emerged that the answer is yes: Human activity is at least partly to blame for global warming. In 2001, the United Nations Intergovernmental Panel on Climate Change (IPCC)—which received input from hundreds of scientists around the globe—issued a report stating "there is new and stronger evidence that most of the warming observed over the past 50 years is attributable to human activities." What activities are these? The burning of fossil fuels, such as coal and oil, and the deforestation of the Earth. Both activities put more carbon dioxide and other "greenhouse" gases into the atmosphere. Warming has resulted from this increase because greenhouse gases trap heat, as you'll see.

It's important to note that there are respected scientists who disagree with this view of global warming. From their perspective, such warming as has taken place may represent nothing more than the random temperature variations that occur on Earth over very long time scales. Under this view, society should not rush to reduce greenhouse gas emissions because it doesn't yet know whether these emissions have anything to do with global warming.

While conceding that this view is supported by some valid arguments, most experts have become persuaded that human activity is indeed playing a part in global warming. What makes them think so? If you look at **Figure 32.18**, you can see that a strong correlation exists between increasing temperatures and rising atmospheric carbon dioxide (CO_2) levels over the last 150 years. If you then look at **Figure 32.19**, you can see temperature trends in the Northern Hemisphere for a much longer period, the last thousand years. Note the strong uptick in temperature that took place beginning after 1900, as civilization was becoming more industrialized, and the even more prominent upturn in the past few decades. This longer-term temperature trend is likewise consistent with longer-term CO_2 trends. The IPCC report notes that atmospheric concentration of CO_2 has increased by 31 percent since 1750 and that the Earth's current CO_2 concentration "has not been exceeded during the past 420,000 years and likely not during the past 20 million years."

A firm rule in science is that correlation is not causation; the fact that two trends are correlated does not mean that one caused the other—that rising CO_2 levels caused global warming, in this case. But by constructing theoretical models of what might be at play, IPCC scientists concluded that the most plausible explanation for the rise in Earth's temperature is that human activity has combined with natural forces, such as solar variation and volcanic activity, to produce the warming we have experienced.

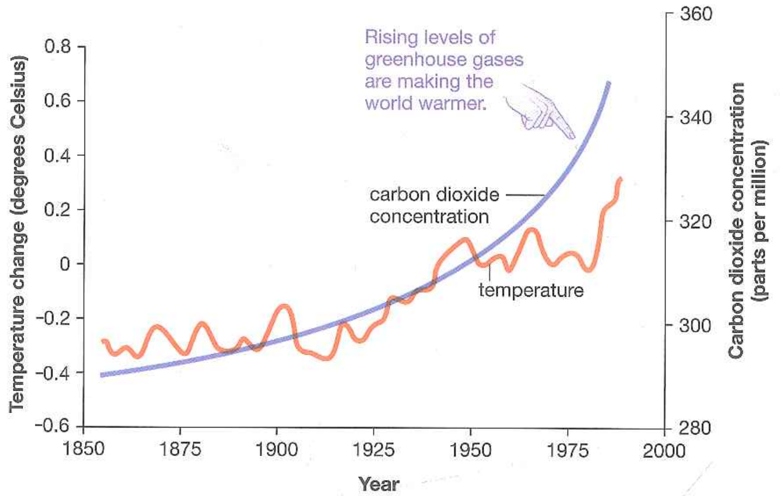


Figure 32.18
Global Warming
Atmospheric carbon dioxide concentration is increasing, and global temperature appears to be as well. It is difficult to be certain that the CO_2 increase is driving the increase in temperature because, over long periods of time, there are great natural fluctuations in global temperature. Most experts have now concluded, however, that rising levels of greenhouse gases such as CO_2 are making the world warmer.

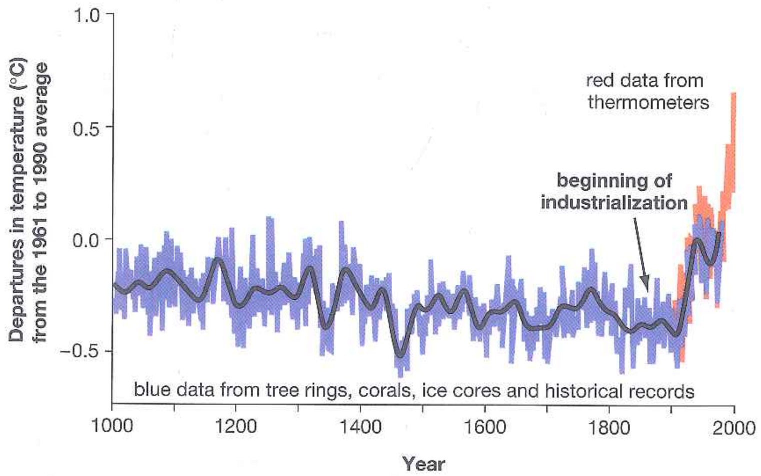


Figure 32.19
Earth's Temperature during the Past 1,000 Years
Using data from such sources as tree rings and ice cores, scientists have estimated average temperatures in the Northern Hemisphere over the last 1,000 years. They concluded that the increase in Earth's temperature in the twentieth century seems to have been greater than the increase that occurred in any other century during the last 1,000 years. Further, the 1990s appear to have been the warmest decade—and 1998 the warmest single year—over the past 1,000 years. (Adapted from *The Third Assessment Report of Working Group I of the Intergovernmental Panel on Climate Change* (IPCC) 2001, *Summary for Policymakers*, Figure 1b.)

What Is the Greenhouse Effect?

Why should the concentration of gases such as CO_2 have anything to do with a warmer planet? Sunlight that is not filtered out by ozone comes to Earth in the form of very energetic, short waves that can easily pass through the atmosphere (**see Figure 32.20**). Once this energy reaches the land and ocean, most of it is quickly transformed into heat that does all the things you've just read about: warms the planet, drives the water cycle, and so forth. This heat ultimately is radiated back toward space. But heat is not short-wave radiation; it is *long*-wave radiation, and it can be *trapped* by certain compounds, among them carbon dioxide and methane.

What Are the Likely Consequences of Global Warming?

All of this leads to the third question that frames the issue of global warming: What will its consequences be? The 1-degree rise recorded so far in Earth's temperature may seem tiny, but consider the effects that *already* appear to have been caused by this small increase. Arctic sea-ice has shrunk by about 6 percent since 1978; ice cover on lakes and rivers in some northern latitudes now lasts about two weeks less than it did 150 years ago; in the European Alps, some plant species have been migrating to higher altitudes at the rate of 4 meters per decade; in Europe and North America migratory birds are now arriving earlier in the spring and leaving later in the fall; and general snow coverage in the Northern Hemisphere appears to have shrunk by 10 percent since 1972. Glaciers around the world, from the Himalayas to the Andes, are shrinking because of

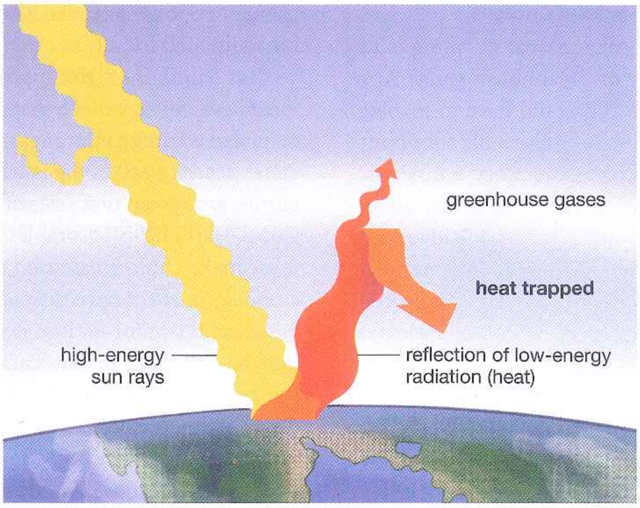


Figure 32.20
The Greenhouse Effect
The high-energy rays of the sun can easily penetrate the layer of gases in the troposphere. However, the lower-energy radiation (heat) that reflects from Earth's surface cannot penetrate the layer of gases as easily. Carbon dioxide and methane thus take on the role of glass panes in a greenhouse: They let solar energy in, but they retain a good deal of heat.

higher temperatures (**see Figure 32.21**). Meanwhile, the ice cap on top of Africa's Mount Kilimanjaro is melting at such a rapid rate that it is expected to disappear in the next 15 to 20 years.

Given such changes, if the temperature increase of the past hundred years were merely repeated in the *next* hundred years, we might worry about what is in store for the Earth. But IPCC research has predicted an increase not of 1 degree Fahrenheit for the coming century, but of 2.7 to 10 degrees. What would such a change mean? A picture of total calamity might come to mind, but the effects actually stand to be mixed. A second IPCC report notes that crop yields in some mid-latitude regions probably will increase because of the greater warmth, as would timber yields in some areas. More water might become available in areas, such as parts of Southeast Asia, where water is scarce now. On the other hand, low-lying parts of the globe may see entirely too *much* water, since melting polar ice is likely to cause a rise in sea levels that stands to displace tens of millions of coastal residents. Insect-borne diseases, such as malaria, can be expected to move both north and south from equatorial regions into formerly temperate areas. Australia and New Zealand are expected to experience a drying trend. Crop yields in current warm-weather regions can be expected to fall. In general, it is the warmer-weather regions of the Earth—and the mostly underdeveloped countries in them—that stand to lose the most from a warmer Earth.

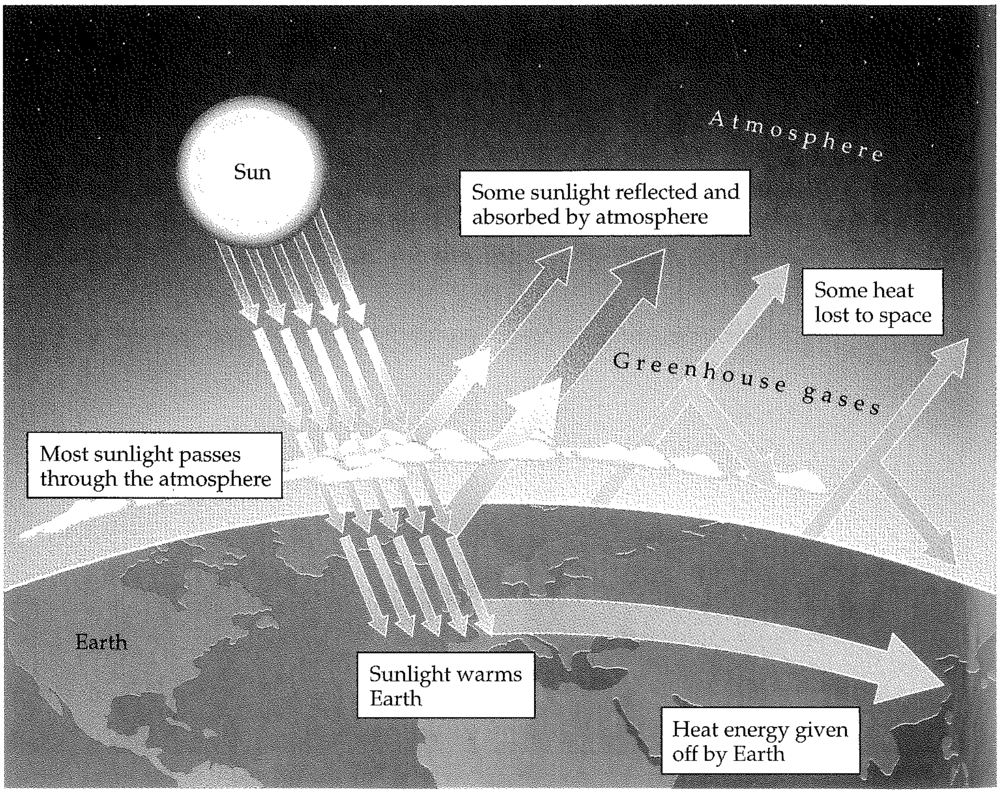
(a) The Qori Kalis glacier 1978 **(b)** The Qori Kalis glacier 2000

Figure 32.21
Warming Planet, Disappearing Glaciers
Global warming is melting glaciers around the world. Peru's Quelccaya ice cap, in the southern Andes, has shrunk by at least 20 percent since 1963. One of the main glaciers flowing from the cap, Qori Kalis, is shown here as it existed in 1978 and then in 2000. A 10-acre lake now exists where the glacier once extended. Its rate of retreat has reached 155 meters or 509 feet per year. This is three times greater than its rate of shrinkage from 1995 to 1998.

12.13 CARBON DIOXIDE AND THE GREENHOUSE EFFECT

No matter how clean an engine or a factory is, as long as it burns coal or petroleum products, it produces carbon dioxide. The concentration of carbon dioxide in the atmosphere increased about 20% in the twentieth century, which most people attribute to global industrialization and the burning of fossil fuels. We generally don't even consider carbon dioxide a pollutant because it is a natural component of the environment and not toxic. Certainly its immediate effect on us is slight. But what about its long-term effects?

The sun emits many different types of radiation, most prominently visible, infrared, and ultraviolet. About half of this energy is either reflected or absorbed by the atmosphere; the light that gets through (mostly visible) acts to heat the surface of Earth. Carbon dioxide and other gases produce a **greenhouse effect** (Figure 12.12). They let the sun's rays (visible light) in to warm the surface, but when Earth radiates heat back toward space, these "greenhouse gases" trap the energy. The same principle applies to what happens in a car left in the sun with the windows closed. Visible light enters through the glass, heats the seats, and the heat is not able to efficiently escape back through the windows. The temperature of the car's interior can rise significantly above the outside temperature. We are lucky to have the greenhouse effect. In the absence of an atmosphere, all of the radiated heat would be lost to outer space, and Earth would be much colder than it is. In fact, just based on the distance from the sun, it is estimated that Earth's average temperature would be a very chilly −18°C.

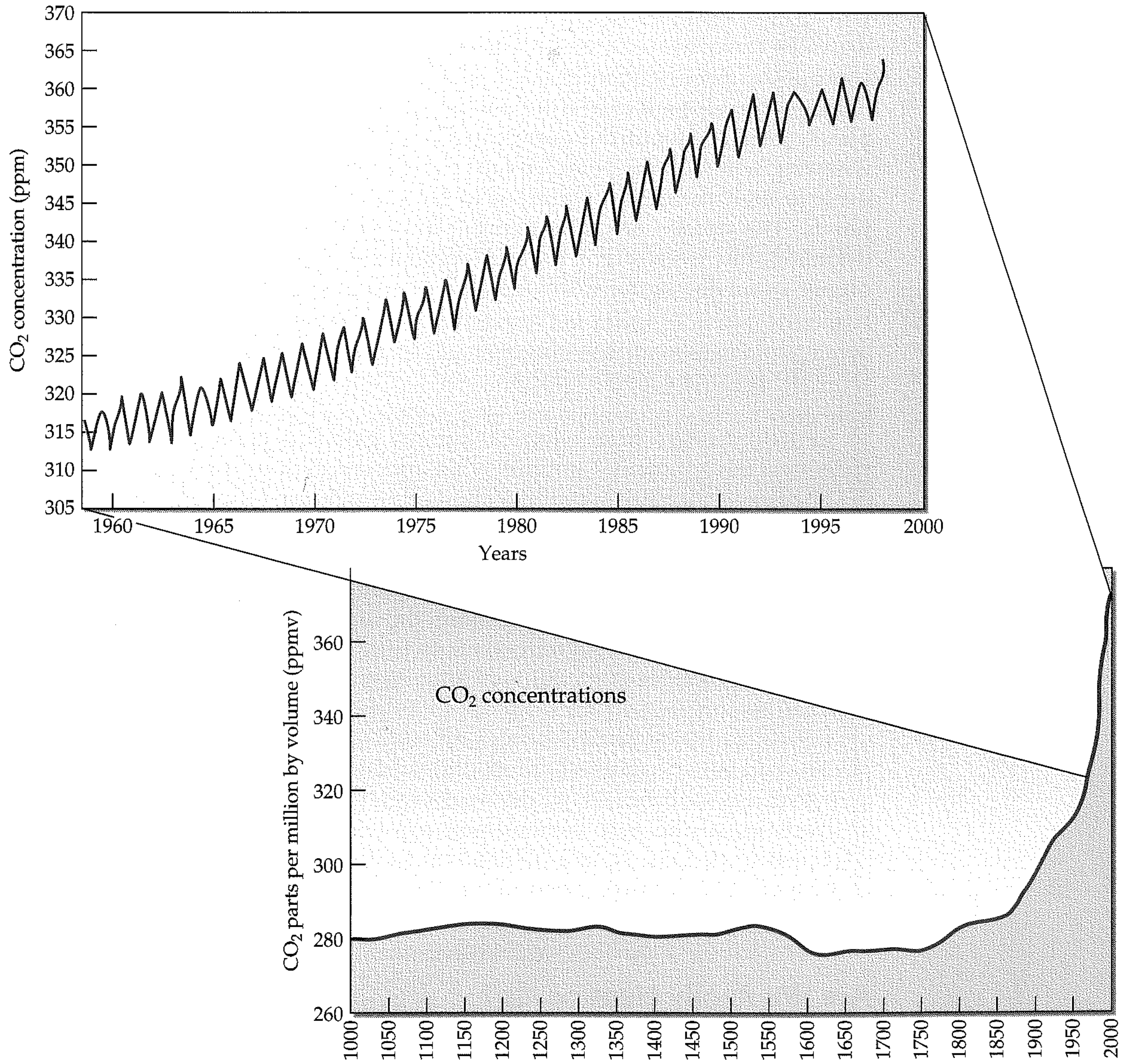


▶ Figure 12.12 The greenhouse effect. Sunlight passing through the atmosphere is absorbed, warming Earth's surface. The warm surface emits infrared radiation. Some of this radiation is absorbed by CO_2, H_2O, CH_4, and other gases and retained in the atmosphere as heat energy.

Global Warming

What many fear is an *enhanced* greenhouse effect caused by increased concentrations of carbon dioxide and other greenhouse gases in the atmosphere. This enhancement could lead to a rise in Earth's average temperature, an effect called **global warming**. Indeed, periods of high CO_2 concentration in Earth's past have been correlated with increased global temperatures.

Human activities add 25 billion t of carbon dioxide to the atmosphere each year, of which 22 billion t comes from the burning of fossil fuels. About 15 billion t is removed by plants, the soil, and the oceans, leaving a net addition of 10 billion t/year. After being relatively constant for many centuries, the beginning of the Industrial Revolution (around 1850) was accompanied by an increase in the global average carbon dioxide concentration (Figure 12.13). The inset shows the carbon dioxide levels as measured at the Mauna Loa Observatory in Hawaii over the last 40 years.



▲ Figure 12.13 The carbon dioxide content of the atmosphere over the past millennium. The increase in carbon dioxide correlates with the beginning of the Industrial Revolution. The inset shows data from the last 40 years, taken from the Mauna Loa Observatory in Hawaii.

Question: What do you think accounts for the cyclic pattern?

Methane, CFCs, and other trace gases also contribute to the greenhouse effect. The concentration of methane in the atmosphere has been increasing since 1977. Although present in much smaller amounts than carbon dioxide, these trace gases are much more efficient at trapping heat. Methane is 20–30 times and CFCs 20,000 times as effective as carbon dioxide at holding heat in Earth's atmosphere. Water is about one-tenth as efficient at trapping the heat, though when present in significant amounts has a noticeable effect. For instance, cloudy winter nights tend to be warmer than clear winter nights, because of the presence of significant amouts of water in the clouds, which acts to trap the heat close to Earth's surface.

Predictions and Consequences

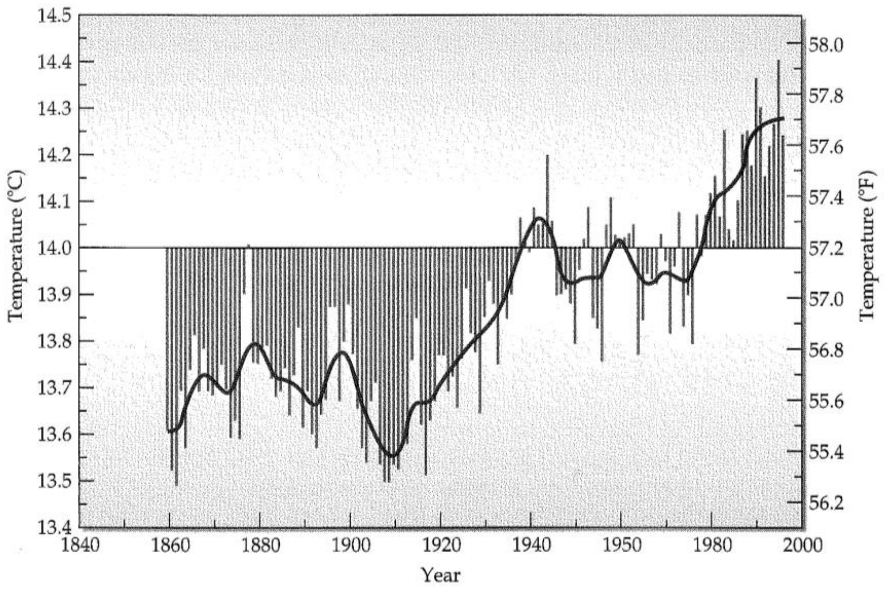
Due to the presence of many complex and interrelated natural variables (clouds, volcanoes, El Niño weather patterns, and the like) as well as estimates of future greenhouse gas emissions, it is difficult to predict the magnitude of warming that will occur. Different scenarios (with different assumptions) have predicted a warming trend of 1–3°C by the year 2100. Most predictions are made by powerful computers, but scientists still are not sure they have input all the needed data. Perhaps this doesn't seem like much, but scientists are concerned (yet not completely certain) about the ramifications of such warming. Some fear that global warming will melt the polar ice caps and flood coastal cities. The ice caps may not need to melt for global warming to be problematic. When water warms, it expands. The oceans are now rising 3 mm/year. Again, this rise may not seem dramatic, but even slight rises in ocean level will increase tides and result in higher, more damaging storm surges.

The Kyoto Conference

In 1997, leaders from over 100 nations gathered in Kyoto, Japan, for the largest environmental summit in history. At issue was the state of the atmosphere, specifically the concentration of greenhouse gases and the industrialization that most believe has contributed to its increase. The Kyoto Environmental Treaty aimed to drastically reduce emissions of carbon dioxide. The final proposal required that countries have a 2012 emission target 5% below their 1990 levels. In fact, the agreement would grant countries "pollution permits." If improvements were made and fewer emissions were produced, one country could sell or trade permits to another country, but the total amount of CO_2 emitted would be limited. In 1998, President Clinton signed the treaty, but it was not ratified by the U.S. Senate. The Bush administration is "unequivocal" in its opposition to the treaty. The United States, which emits about 30% of the world's greenhouse gases, will not ratify the treaty mainly because there were no enforcement procedures in place for developing nations, such as China and India. "It is not in the United States' economic best interest," the administration believes.

Are We Really Heating Up?

Though it is quite clear that both the surface temperatures and atmospheric CO_2 concentrations have risen during the last half of the twentieth century, many aspects of global warming present some significant controversy. One of the major difficulties is acquiring data on the state of the atmosphere and global temperatures in the past. Surface temperature measurements have definitely been on the rise for the past several



◀ **Figure 12.14** Surface temperature variations over the past 135 years.

decades (Figure 12.14), but skeptics of the severity of the situation point to several pieces of evidence that seem contradictory to the data presented above:

- Many of the surface temperature measurements are taken in urban areas and are subject to the so-called heat island phenomenon and therefore overestimate the surface temperature.
- Satellite data show that portions of the upper atmosphere have actually cooled slightly in the last 20 years.
- CO_2 levels have been as high as or higher than current levels long before human industrialization.
- Carbon dioxide levels seem to be leveling off in the past 15 years or so (see inset to Figure 12.13), even though the rate of fossil fuel combustion has continued to increase.

So what is the answer? Perhaps what is most clear is that the chemistry of the atmosphere, the interconnected elemental cycles (oxygen, carbon, nitrogen), and the interactions that gas molecules have with radiation is an incredibly complex phenomenon. The science is made even more difficult because of the immensity of the laboratory (the entire Earth) and the lack of ability to perform controlled experiments. What can and should be done? First, it is unlikely that imposing drastic, economically disastrous limits on energy consumption will have the desired effects. Carbon dioxide is only one of several gases implicated in the warming trend. Second, the opposite extreme, denial of the global warming problem, is equally unwise. Global climate change and its causes are an extremely complex problem and could have catastrophic effects on human civilization.

12.14 THE ULTIMATE POLLUTANT: HEAT

Hybrid cars—vehicles powered by a combination of gasoline- and battery-powered engines are sometimes advocated as one step in the solution to air pollution. They could help to reduce air pollution in urban areas. But hybrid cars require electric power, and electric power requires power plants. Conventional power plants burn coal, gas, and oil. It might be argued that replacing cars that run on fossil fuel with ones that run partially on electricity would serve only to change the site of the pollution and perhaps spread it out a bit, which would be a benefit for highly populated urban areas. Efficiency plays a role, however; if an electric vehicle or a hybrid is more efficient in its use of fuel, there may be a net benefit.

There is one pollutant we cannot avoid: heat. According to the second law of thermodynamics, in any energy conversion some of the energy winds up as heat. All power plants dump residual heat into the environment as they produce electric energy, and this heat may be the ultimate pollutant. Even now, human structures and activities often make urban areas "heat islands" that are 4–5°C warmer than the surrounding rural areas.

2.6.2 Correlation

The covariance is useful, but has dimensions. A covariance between height and weight of 7.6, say, means one thing in centimetre-grams and another in metre-kilograms. A better measure of the relation between two variables is the *correlation coefficient*, ρ. This is defined as

$$\rho = \frac{\operatorname{cov}(x, y)}{\sigma_x \sigma_y} \tag{2.20a}$$

$$= \frac{\overline{xy} - \bar{x}\bar{y}}{\sigma_x \sigma_y}. \tag{2.20b}$$

ρ is a number between -1 and $+1$. If ρ is zero then x and y are *uncorrelated.* A *positive* correlation means that if a particular x happens to be larger than the mean $\bar{x}$, then y will also (on average) be larger than the mean $\bar{y}$. For a negative ρ, a larger x will imply a smaller y. If ρ is 1 (or -1) then x and y are completely correlated: if you know the value of one that specifies precisely the value of the other. ρ is dimensionless, and is unaffected by shifts in the origin or by changes in the scale for x or y (see Figure 2.4).

Here are some real examples of correlation, from the performances of a class of second-year students who took exams in thermal physics and quantum mechanics, and were also assessed on their laboratory work.

Figure 2.5 shows the marks obtained in quantum mechanics (horizontally) and thermal physics (vertically). As one would expect, students who do well in one tend to do well in the other, and the correlation coefficient is 0.7.

Figure 2.6 shows the marks of the same students in laboratory work, again

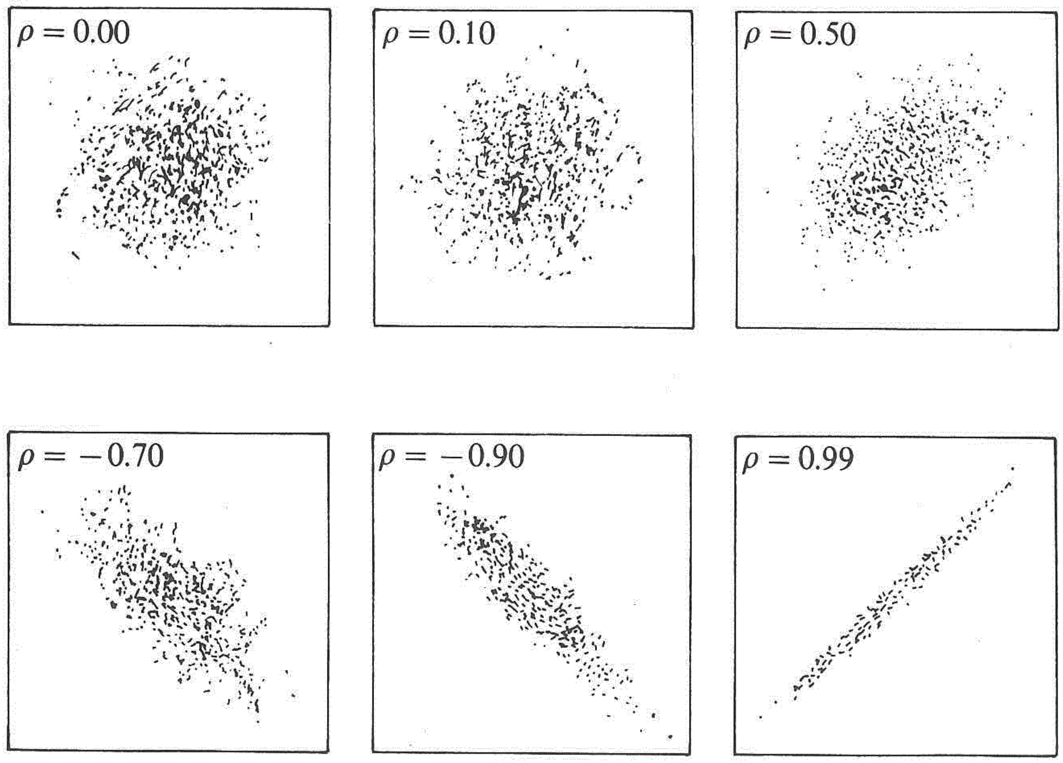


Fig. 2.4 Scatter plots showing examples of correlation. The scales and origin of the axes are irrelevant (see text) and are therefore not shown.

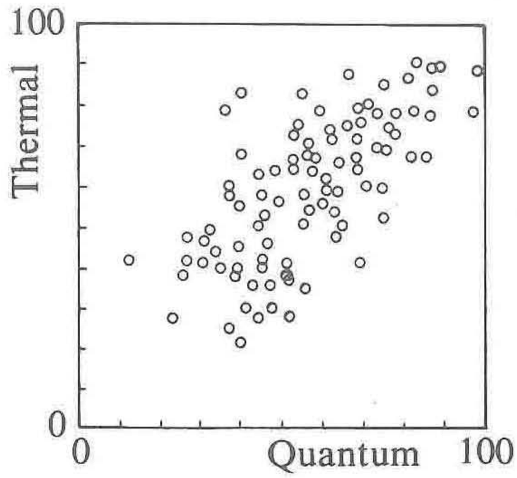


Fig. 2.5 Marks in quantum mechanics and thermal physics.

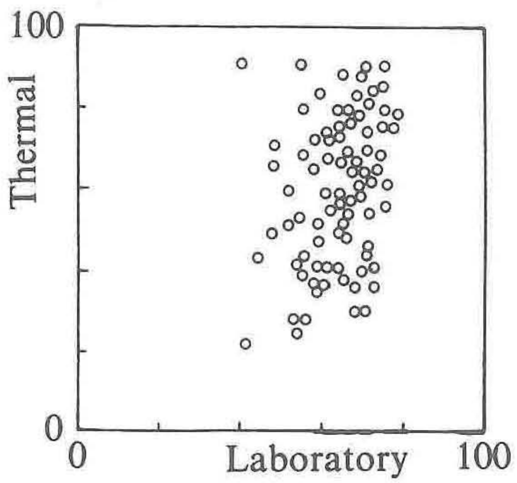


Fig. 2.6 Marks in laboratory and thermal physics.

compared with thermal physics. The tendency for students to do well or badly in both is still present, but much weaker, and ρ is only 0.3.

Problem

The marks of twelve students in classical mechanics and quantum mechanics are as follows:

Classical	22	48	76	10	22	4	68	44	10	76	14	56
Quantum	63	39	61	30	51	44	74	78	55	58	41	69

Calculate the two average marks, and the correlation.