QUESTIONS:

1. According to Milankovitch’s theory for climate change, the inclination of the earth’s rotation axis varies between approximately 22° (smallest inclination) and 25° (largest inclination) over thousands of years (a cycle of about 41,000 years). Complete parts a – e of this question which investigates the potential effect of this factor in influencing climate.

a. The drawings A and B below show the earth’s rotation axis, the earth’s equator, the direction of sunlight and the earth’s orbital plane. The perpendicular to the orbital plane is also indicated. The plane, like a tabletop passes through the centers of the earth and sun and represents the plane in which the earth orbits the sun. The inclination of the earth’s axis of rotation is the smallest angle between the perpendicular to the orbital plane and the earth’s rotation axis. Based on this definition for angle of inclination, label which lettered diagram shows a small angle of inclination and which shows a large angle of inclination. NOTE: The inclination angle has been exaggerated for these drawings.

b. We can approximate the region of the earth’s surface which experiences direct sunlight (sun appearing directly over head at sometime during the course of the year). This region of greatest solar heating is called the torrid zone. Approximate the extent of the torrid zone for each drawing in part a above. Using a straight edge draw a line parallel to the equator in each drawing through the point where the orbital plane crosses the earth’s surface (edge of circle). As a guide to start, these points have been marked on drawing A with a small x. You should end up with two parallel lines one on either side of the equator. Do the same for drawing B.

c. On each drawing shade in the region between these two lines. This will represent the region of maximum heating on a yearly basis for the given angles of inclination.

d. The narrower the torrid zone the smaller the contrast between winter and summer in mid to high latitudes. If this were the only climatic influence it would result in warmer winters and cooler summers than we now experience. A warmer winter in this sense means only that the average temperatures are higher than we now experience, however, there may be nearly as many days below 32°F as there are today during winter. The warmer winter would mean more moisture in the atmosphere, and would probably result in the formation of more snow and ice cover forming in the winter. The cooler summer would result in less melting of the snow and ice formed during the previous winter. Would mild winters followed by cool summers most likely tend to (increase or decrease) the development of glaciers? 

2. Milankovitch’s Astronomical Theory also finds evidence of a change in the shape of the earth’s orbit over a cycle of about 100,000 years. The orbit changes from a somewhat elliptical one to todays nearly circular shape. Complete the following parts a – c of this question which investigates this factor.

a. When the axis of rotation of the earth is tilted toward the sun it is summer in that particular hemisphere, and when it is tilted away from the sun it is winter in that particular hemisphere. For the drawing below a short line has been drawn beside each hemisphere. On each of these lines indicate whether that particular hemisphere is experiencing winter or summer.

b. For planetary orbits, the point in the orbit when a planet is closest to the sun is called the perihelion and the farthest point is called
the **aphelion**. Label these terms on drawing 2, of part c below.

c. Considering distance as the **only** factor, which of the following drawings, drawing 1 or drawing 2 shows the planet experiencing the greatest change in energy received from the sun on a **yearly** basis? Explain.

![Diagram](image)

1. LARGE DISTANCE 2. DIFFERENCE

3. We will now consider the effects of both axial inclination and the shape of the planetary orbit together. Complete parts a - f of this question which considers how the inclination of the rotation axis may affect the severity of the season, and then how the distance between the earth and sun may amplify or moderate the effect of inclination.

   a. For each planet position shown in the diagrams below indicate whether it is winter or summer in the northern hemisphere.

   Write in the correct season on the lines beside the northern hemisphere for each planet position. The earth's orbit is shown here with its greatest elliptical shape highly exaggerated. None of the drawings below represent the conditions today where the orbit of the earth is fairly circular.

   ![Diagram](image)

   b. For each summer position you have marked on the drawings above, place a number from 1 to 4 above the word summer, to indicate the relative degree of coldness or hotness for that particular summer. The number 4 represents the hottest and the number 1 represents the coldest. **To do this, first consider the relative degree of hotness or coldness based only on the amount of inclination of the rotation axis (large inclination versus small inclination).** Once you have determined this, then consider the distance the planet is from the sun, and decide how this will either intensify or moderate the effect of inclination of the rotational axis. We will assume that inclination is the primary factor and distance from the sun the secondary factor for the earth.

   c. Do the same analysis as in part b but this time mark the winter positions and continue as above, where 1 is the coldest winter and 4 is the warmest winter.

d. Based on the extent of glaciation shown in the following drawing, what seasonal conditions could have caused this? That is, could this circumstance be caused by warm or cool winters followed by warm or cool summers?

![Diagram](image)

e. Which numbered diagram associated with part a might represent the conditions leading to the glaciation as shown in the above diagram?

f. Once a major ice age begins, how might the growth of large ice sheets contribute to more global cooling, and hence to a deepening of the ice age? Higher albedo of ice causes positive feedback

4. The next sequence of drawings represents the movement of land masses across the earth over the last 200 million years as proposed by the modern theory of continental drift. Considering latitude as the primary control of climate, complete the following parts a - g of this question.

   a. Drawing 1 shows the earth as it may have appeared 200 million years ago. Several of
The major land masses have been labeled with letters. Using the climate terms polar, temperate, and tropical, indicate which term best approximates the climate of each land mass shown in the region marked by the letters. For this question we will assume polar climates are located between 60°-90° latitude, temperate climates between 30°-60° latitude, and tropical climates between 0°-30° latitude. If you find your answer can be one or the other list both choices.

A. Polar  B. Tropical  C. Temperate  
D. Temperate  E. Polar  F. Temperate

1. 200 MILLION YEARS AGO

b. Drawing 2 shows how the earth may have appeared approximately 65 million years ago. Again using the climate terms listed above indicate which term best approximates the climate of each land mass, in the region marked by the letters.

A. Temperate  B. Temperate  C. Tropical  
D. Temperate  E. Temperate  F. Tropical

2. 65 MILLION YEARS AGO

c. Drawing 3 shows how the earth surface appears today. Again using the climate terms indicate which term approximates the climate of each land mass, in the region marked by the letters.

A. Tropical  B. Temperate  C. Tropical  
D. Temperate  E. Tropical  F. Tropical

3. PRESENT DAY

d. List four land masses (by name) which appear to have regions that have gone from a polar type climate to a tropical type climate over the past 200 million years.

1. Africa  
2. Australia  
3. Asia  
4. South America  

e. Geologists have found evidence of ancient glacial movement in the form of striations on rocks in Southern Africa. Even though Africa today has a tropical climate, explain how this could have occurred.
South Africa was located closer to South Pole but drifted equatorward.

f. If Antarctica exhibits evidence of once having had tropical plants, at what latitudinal location might Antarctica have been located prior to 200 million years ago? 0°-30°S

Place a prominent dot (●) approximating your continental location on each of the maps above starting with drawing 3 and working back through drawings 2 and 1. Has the climate of your location changed over the last 200 million years? Yes. Tropical changed to Temperate

Variability in the number of sunspots is an observed characteristic of the sun. The earliest records found in Europe and the Far East con-
firm this variability. Complete parts a - h of this question which investigates this variability and how it may affect climate.

a. The chart below shows how the average number of sunspots have varied in number from around 1650 up to modern times. Based on this data determine whether the following dates are near those of sunspot maximum or sunspot minimum.

**VARIATIONS IN SUNSPOT NUMBER WITH TIME**

![Sunspot Number with Time Graph]

- 1780 max 1870 max 1965 min
- 1810 min 1959 max 1990 min (Estimate)

b. In the early 1900's while studying old sunspot records, Walter Maunder of the Royal Greenwich Observatory in London, noticed a long period of very low sunspot activity. This period of time is referred to as the Maunder Minimum. Using a double ended arrow (---), mark on the sunspot chart the approximate period corresponding to the Maunder Minimum.

c. The **Maunder Minimum** occurred during the years **1640** to **1710**

This is a period of approximately **70** years.

d. The chart below shows the relative temperature variations during winter in Western Europe for the last 1000 years. Mark an H on the graph showing any point of relatively high temperature. Mark an L showing any point of relatively low temperature.

![Winter Severity Chart]

- The **Maunder Minimum** is approximately corresponding to the Maunder Minimum from part b.

f. Although we must be extremely careful in making generalizations based on limited data, at times this may be the only information available. Based on the limited data above what **appears** to be the relationship between periods of extended low sunspot activity and temperature in Western Europe?

**Cooler Temps**

- It has long been recognized that by analyzing tree rings we can learn about the growing season in the year the tree produced a "ring of growth". These rings can be easily studied from cross-sections of cut trees. In a good growth year the tree produces a thicker ring than in a poor growth year. The analysis of tree ring data suggests two small climatic events occurred in Europe. One event called the **Spörer Minimum**, was a cool period in Europe occurring between 1450 and 1540 A.D. The other event called the **Medieval Maximum**, was a warm period in Europe and occurred during the 12th century (1100-1199). Using double ended arrows mark and clearly label the Spörer Minimum and Medieval Maximum on the chart with part d.

g. Although we have no reliable records of sunspot counts during this period, what would you predict to be the sunspot activity during these periods, if there is a cause and effect relationship between temperature and sunspot activity? Use the terms **high sunspot numbers** or **low sunspot numbers** in filling in the answers below.

- **Spörer Minimum** **Low**
- **Medieval Maximum** **High**

6. The graph below shows the average global atmospheric concentration of CO₂ in parts per million (ppm) as measured at scientific stations located in the northern hemisphere. Complete parts a - d of this question.

**CO₂ CONCENTRATION**

![CO₂ Concentration Graph]

- Using a double ended arrow (---) mark on this chart and clearly label, the period ap-
a. What was the CO₂ concentration (ppm) in 1970? 325 1985? 347

b. Has the concentration of CO₂ increased or decreased over the time interval shown on the graph? Increased

c. Assume the rate of increase in CO₂ concentration remains essentially linear and the rate of increase from 1980 continues to be approximately 1.5 ppm per year. Based on this, calculate the expected CO₂ concentration for the year 2050.

\[ 20 \times 1.5 = 30 \]
\[ \sim 377 \text{ ppm} \]

d. List three significant sources of CO₂ emission that are responsible for its increasing concentration in the atmosphere.

**Various Answers**

7. The long term affect on the earth's climate system of increasing concentrations of greenhouse gases other than water vapor, such as carbon dioxide (CO₂), methane (CH₄) and chlorofluorocarbons (CFC-11, CFC-12) and nitrogen oxides is the subject of continuing debate. The greenhouse molecules are not equally effective in "trapping" heat energy in the lower atmosphere. Current evidence suggests that each CH₄ molecule is about 30 times more effective in absorbing infrared terrestrial radiation (heat energy) as compared to the CO₂ molecule. CFC molecules are on the order of 1000 times more effective while some nitrogen oxide molecules are about 200 times more effective. Complete parts a - g of this question.

a. List these four molecules in order, from greatest to least in terms of their potential for "trapping" heat in the lower atmosphere and hence affecting global warming.

CFC-11, NO₃, CH₄, CO₂

b. If on a molecule for molecule basis the CO₂ molecule is the least effective, then why is there more concern about current levels of CO₂ in the atmosphere than any of the other greenhouse molecules?

much greater concentration

c. Careful analysis of air trapped in recent glacial ice sheets show that CO₂ concentrations during the interglacial warm periods varied from 270 to 300 ppm. The CO₂ concentration however, was about 180 ppm during an ice age. Does this evidence support a correlation between CO₂ concentration and global climate change? What is this correlation?

Yes. More CO₂ = warmer climate

d. The graph below shows how the concentration of CH₄ has changed over recent time. Has the CH₄ concentration increased or decreased over this time interval? **Increase**

\[ \text{CH₄ CONCENTRATION} \]

\[ \text{Graph showing increase in CH₄ concentration over time} \]

e. Based on the changing concentrations of CO₂ and CH₄, how do you expect this trend to ultimately affect global air temperature?

**Increase air temps**

f. The graph below indicates the average global temperature difference for a particular year as compared to the 1950 - 79 base. What appears to be the general trend in global air temperature from 1900 through the 1980's (increasing or decreasing)? **Increasing**

\[ \text{AVERAGE GLOBAL TEMPERATURE DIFFERENCE} \]

\[ \text{Graph showing increasing global temperature trend} \]

g. Describe why the trend of part f might be expected if there is a cause and effect relationship between increasing concentrations of greenhouse gases and global air temperature. (There is currently considerable disagreement in scientific circles, on this very issue.)

**Man-made increases in these gases**

8. For years people have speculated that material injected into the atmosphere might significantly affect the global temperature. Several investigators have concluded that the injection of large quantities of volcanic aerosols and gases into the atmosphere may have been responsible for a number of short-term (1-3 year) temperature fluctuations in the atmosphere. There is, however, no conclusive evidence linking volcanism with periods of major glaciation. In fact, geologic records show that millions of years ago large amounts of volcanic aerosols and
gases were probably injected into the atmosphere. This particular period of prolonged volcanism had little effect in producing or sustaining major glaciation in North America. As always the data may be subject to new interpretations as other evidence surfaces, so goes the nature of scientific investigation. Complete parts a-f of this question investigating volcanism and its possible effects on climate.

a. List three different sources of particulate matter found in the atmosphere.

b. Volcanic eruptions are of two main types: effusive eruptions in which lava predominates and explosive eruptions in which large amounts of volcanic ash and gases are injected into the upper atmosphere. Which type can have the larger worldwide climate effect? Explosive


d. What evidence do you see in the photograph suggesting the cloud is spreading through the atmosphere with the passage of time?

On April 4, 1983 at 7 a.m. (EST), the El Chichon smoke plume is visible as an intense white circular feature.

Approximately 12 hours later, at 7 p.m. (EST) the extent of the El Chichon smoke plume is still evident on this satellite photograph.

e. On August 27th and 28th, 1883 one of the mightiest volcanic eruptions in modern times took place on a South Pacific Island. The volcano was Krakatoa. The explosion resulted in total darkness during mid-day for hundreds of square miles surrounding the island. At Bandar some 200 miles NW of Krakatoa the mid-day temperature is normally 90°F, but at 2:00 p.m. on August 28th, 1883, it was 65°F. Explain what probably caused this unusually low mid-day temperature.

Ash blocked sunlight

f. Fine dust particles in the lower atmosphere (troposphere) precipitate out in a few days, but particles injected into the stratosphere can remain there for several years. It is known that the stratosphere also contains very strong horizontal winds. Explain how these two factors might make it possible for volcanic activity in isolated regions of the world to affect the entire globe.

9. The graphs 1-3 on the right show how direct sunlight and diffuse sunlight (sunlight scattered by microscopic "particles" in the atmosphere) were effected by a volcanic eruption. The eruption took place in 1963 on the island of Bali in the Pacific Ocean northwest of Australia. Complete parts a - h of this question.

a. Did the sunlight (graph 1) reaching the surface increase or decrease following the eruption? Decrease

b. Circle your evidence from graph 1 and explain your answer in terms of the effect of particulates (ash, dust, etc.) in the atmosphere. Particulates blocked sunlight

c. Did the diffuse sunlight (graph 2) reaching the surface increase or decrease following the eruption? Increase

d. Circle this on graph 2 and explain your answer. More particles means more "scatters."

e. Was the total decrease (graph 3) in sunlight reaching the surface as large as you might have suspected it would be? No

f. Circle this in graph 3 and explain your answer. Only a slight overall decrease.

g. If the Bali event is assumed to be somewhat "typical" of explosive volcanic events, why is it that these events may not significantly reduce the total sunlight reaching the surface?

Same answer?

h. What might the Bali volcanic event suggest about the significance of volcanism in influencing long term climate change?

Not a long-term change.