Venus and Earth Role Play

You are one of the organizers of this conference. You have been given the task of summarizing the conclusions of discussion that has taken place. You will need to outline the argument for why Earth and Venus are so different. Here are a few of the things you should include, if conclusions have been reached on these points:

1. Why are the atmospheres of Earth and Venus so different? In particular, where has all of the carbon dioxide that was presumably in the atmosphere of the early Earth gone?

2. Why does carbon dioxide in the atmosphere make it difficult for solar radiation that heats a planet to get out?

3. Where has most of any water that Venus originally had gone?

Background Briefing

This activity introduces the concepts of comparative planetology. Why do planets in our Solar System show such strong differences to each other? What events in their histories have been most influential in setting them on diverging courses? Particularly as humankind has arrived at the point where our activities can have an impact on the Earth as a whole, this has become a crucial question. Could something we do start Earth off in an uncontrollable process of irreversible change?

In this exercise we focus on the “sister planets” Earth and Venus. They are almost the same size and at only slightly different distances from the Sun. Yet, if Earth is in some sense a “heaven”, as far as life is concerned, Venus can only be described as a hell. With surface temperatures sufficient to melt lead, a crushing CO₂ atmosphere nearly 100 times the pressure of Earth’s, and sulfuric-acid clouds, Venus is about as inhospitable place as one could imagine. Why did Venus and Earth take such different paths?

You are among several groups of scientists that have gathered together to try to figure this out. This all happened by chance, when several of you were talking over lunch while judging a local science fair (you are in such diverse fields that you normally wouldn’t even be talking to each other). In any case, one thing led to another, and you have all agreed to have an informal conference to see if your varied experiences can shed some light on this amazing difference between Earth and Venus.

Your goal is to put all the information you will learn from the other groups together, to make a coherent theory of the Mystery of Venus: why conditions on Venus are so different from those on Earth, when the masses, radii and distances from the sun of the two planets are so similar.
You are plant biologists, and your special field of expertise is carbon dioxide (CO\textsubscript{2}). Carbon dioxide is vital to all plant growth as it is used in photosynthesis, and you have been researching where it comes from and where it goes to.

You have been experimenting with growing exotic fruits near volcanoes. All volcanoes emit large amounts of carbon dioxide: the more active, the better. In the course of an adventure-filled few years, you have perfected fragrant “Popocatapetl Peaches” from the vast volcanoes of central Mexico, giant “Kilauea Kucumbers” from the Big Island of Hawaii, and the hallucinogenic “Fuji Fungi” from Japan (currently banned in the U.S.) But your proudest research triumph has been, without a doubt, the prize-winning “Chateau Vesuvius” 1999 vintage….

In the process of your research, however, you became somewhat perplexed. So much carbon dioxide is being emitted by the world’s volcanoes that you would expect that the Earth’s atmosphere would be much thicker than it is, and mainly composed of CO\textsubscript{2}, rather than the nitrogen and oxygen that are its biggest constituents. Where has all the carbon dioxide emitted by all the world's volcanoes since the Earth formed gone? Of course plants absorb CO\textsubscript{2} and produce oxygen (O\textsubscript{2}) in photosynthesis, but animals do the reverse, and, anyway, most of the CO\textsubscript{2} absorbed by plants ends up back in the atmosphere when the plant dies and decays or is burned.

After exhaustive (and exhausting) research, you have discovered that carbon dioxide is very soluble in water. Most of the CO\textsubscript{2} produced by volcanoes ends up being dissolved in the sea. You have taken samples of water from all the world’s oceans. When you boil the samples, the carbon dioxide is released and can easily be measured. You have found that the oceans can absorb a lot of CO\textsubscript{2}, but not nearly enough to account for the amount that you calculate must have been produced over the age of the Earth. There must be more to the story. You are beginning to wonder if there is some way for the oceans to cycle CO\textsubscript{2} into something else, without putting it back into the atmosphere. Or was there some other way of taking CO\textsubscript{2} out of the air in the past? Or both?
Soft-Drink Industry Scientists

You work for a major soft-drink manufacturer. You have mostly been involved in developing new varieties of carbonated beverages for the Asian market, where your employer sees the greatest opportunity for future growth. Your team has developed the very successful “Chiang Mai Cola” and “Shanghai Surprise,” and you have been rewarded with a new research lab with the latest equipment, as well as a certain amount of freedom to explore new directions for soft drinks.

Everyone in your industry is aware that, especially in Western Europe, North America, and Japan, which still account for the bulk of your sales, populations are aging and soft-drink consumption falls off among older people. You have just come up with the idea of incorporating calcium into a drink to be promoted to seniors—if you can pull this one off successfully, your team should be in line for big bonuses and maybe even a bigger research lab with lots of research assistants!

However, you have run into a snag that has you pulling your hair out day after day. A lot of calcium compounds just don’t dissolve very well in water. And for those that do, as soon as you inject carbon dioxide to make the drink fizzy, the liquid becomes cloudy with fine particles that settle out slowly onto the bottom of the container. You confirm that this is calcium carbonate—the same stuff that makes up limestone, coral reefs, and clam and oyster shells. The dissolved calcium combines with the dissolved CO$_2$, and the resulting calcium carbonate is insoluble. Calcium is a pretty common in the Earth’s crust—after all, cows seem to get plenty of it just by eating grass. But there doesn’t seem to be any good way to make a calcium-rich soda that people would be willing to drink. Maybe you’ll just have to advise the advertising branch to promote root-beer floats to the older crowd and have your research team move onto something else….
Coal Experts

You are a team of top researchers from the Fossil Fuels Institute, funded by the coal, gas and oil industries. Because of this funding, you have better labs and more accurate equipment than almost anyone else at this conference: you drive nicer cars, live in bigger houses, and can investigate more difficult scientific problems.

You have been doing research on ways to spot brushfires at a very early stage: long before they are dangerous. If you can do this, many of these fires can be put out before they hurt anybody.

Many gas pipelines, coal mines and oil fields are in regions threatened by brushfires, and such fires can be very costly: if a coal field catches fire, it can smolder for decades. This is why your employers are paying for this research. You hope, however, that your research will be of great use to many other people—it could save a lot of people's lives. Whenever anything gets hot, it emits infrared radiation. People are quite hot, for example, and their skin constantly shines with infrared radiation: this is how people buried in earthquakes often are found and rescued. Brushfires are hotter still, so they will emit very intense infrared radiation.

You plan to use several satellites to scan the entire U.S. several times a day with an infrared camera. All the bright spots will be potential brushfires. Unfortunately, there are a few problems. Infrared radiation penetrates clouds quite well, so you can see fires all the time. But it doesn't penetrate water vapor very well: if a fire breaks out in a very humid region, all the infra-red radiation is absorbed by the water vapor, and you don't see anything. Infrared is also blocked by carbon dioxide, so it is hard to spot bushfires near big power stations, because of all the carbon dioxide they emit when burning coal.

Before you left for this conference, your boss called you in to remind you that you work for the fossil fuel industry, so if you hear of any scientific results that suggest that fossil fuels are dangerous, try and suppress these results. If the conference comes up with a result harmful to your employers, you can kiss your jobs (and nice houses and cars) goodbye…
Space Warfare Experts

You work for a top-secret government lab, studying space warfare. Indeed, the lab is so secret that when you retire, all memory of it will be wiped from your brain, and replaced with fake memories of lives as turnip farmers.

The big problem in space warfare is not in destroying enemy spacecraft: your colleagues in the laser section down the corridor have got plenty of ways of doing that. No, the problem is finding the enemy in the first place, especially if they are in black-painted, radar-absorbing stealthy spacecraft.

The way you figure it, any spacecraft is going to be receiving lots of heat. Firstly, any motors, engines, machines, nuclear reactors, laser guns or cosmonauts on board will generate heat. Secondly, visible light radiation from the Sun will be constantly hitting the spacecraft, and the energy from this solar radiation (which is in the form of visible light) will be absorbed by the object.

If all this heat is being added to an object in space, it will continuously heat up, unless it can get rid of the heat in some way. On Earth, a cool breeze or a spray of water could cool it down, but in the vacuum of space, there is nothing of the sort to conduct heat away. The only option for getting rid of heat energy in space is to radiate it. Luckily, every object radiates infrared heat radiation all the time: you are all doing it as you sit there reading this. So is the conference hall, the grass, trees and buildings outside.

So, every object in space will have to radiate infrared radiation. The hotter it is, the more it will radiate. If it cannot radiate infrared radiation, for whatever reason, it will just go on getting hotter and hotter, until eventually it is so hot that the infrared radiation it does emit balances the energy it receives from both internal and external sources. As it happens, you are currently using this knowledge to build infrared sensitive cameras. This should enable you to spot most enemy spacecrafts. If they don't try and keep the infrared radiation in, they will stand out like a sore thumb against the cold darkness of space. If they do try and bottle up their infra-red radiation, by using lots of insulation, the spacecraft will just get hotter and hotter until the cosmonauts and/or equipment inside start frying! But don't tell any of your colleagues too much about this part of your work—you never know who might be a French spy….
You are astronomers, unlike most of the others at this rather strange conference. In fact, you are experts at one of the most difficult astronomical problems: measuring the exact chemical composition of something you cannot even touch. You point your telescopes at distant objects, and by a very detailed study of the wavelengths of the light that you see, you can often determine the chemistry of something far out in space. Strange but true!

You've recently been turning your telescopes on Venus. The data looked quite boring at first: the atmosphere was mostly made of lots and lots of carbon dioxide (CO₂), with a few clouds of sulfuric acid droplets to add variety. When you looked more closely, however, a rather surprising fact came to light. You detected only exceedingly tiny amounts of water on Venus. And in this tiny amount of water vapor, you find that the hydrogen is represented by an astonishingly high proportion of its heavier isotope (i.e., hydrogen atoms that have masses twice that of normal hydrogen).

How come so much of this heavy isotope is present, but almost no water? You suspect that the water must have escaped from Venus or been destroyed, leaving behind only these tiny traces of isotopically enriched water vapor to show that it was once there. You calculate that, once upon a time, Venus must have had oceans. But where did they go? What went wrong?
Environmental Scientists

You all grew up downwind from a tannery; as a result, you have dedicated your lives to the downfall of companies that pollute the atmosphere. You spend many of your weekends climbing smokestacks to plant Greenpeace banners on top, or chaining yourselves to factory railings.

On weekdays, you work for a government research institution, trying to invent ways of testing the air over factories to see if companies are breaking anti-pollution laws. The problem is this: imagine you suspect that a company is pumping out noxious chemicals. You could get a warrant and go and inspect them, but by the time you do all the paperwork, they might have switched off the offending process. What is needed is a way of seeing what is in their fumes, from outside the factory gates.

You have figured out a brilliant way of doing this. You set up a bright light, emitting lots of visible light radiation and infrared radiation, on one side of the factory. Then you set up a spectrometer on the other side, and you see which types of light make it through all the polluted air.

To make this process work, you need to know which pollutants absorb which types of light. You have spent years shining beams of various sorts of radiation through test tubes full of strange gas mixtures. And after years of dogged work, you have concluded that gasses fall into four distinct categories.

1. **Completely Transparent**: Many substances, including nitrogen, oxygen, xenon, hydrogen and helium, are essentially transparent to both visible light radiation and infrared radiation.
2. **Completely Opaque**: Some substances, particularly small droplets of water, of sulfuric acid, and of hydrochloric acid, block both visible light and infrared radiation equally.
3. **Visible Light Blockers**: Any tiny solid particles, such as diesel fumes, interstellar dust, smoke from burning forests or cities, or tiny dust grains picked up in dust storms, are rather good at blocking visible light radiation, but are poor at blocking infrared radiation.
4. **Infrared Blockers**: A variety of molecular gasses, including water vapor, methane, and carbon dioxide, block infra-red radiation but not visible light radiation.

So far, you have used this technique to prove that a large local manufacturer of hot water systems was using illicit methane-based solvents to clean their pipes: infrared radiation was being severely blocked as it passed over their factory, while visible light radiation was making it through unscathed. You are now working on a visible light based sensor to test whether diesel truck engines are correctly tuned up, and not emitting too many tiny solid particles of incompletely burnt fuel. Unless the truck companies persuade the government to shut down your research program…. 
You are physicists employed by a company that builds water heaters and showers. You have built up a worldwide reputation for your expertise in the properties of hot water at different temperatures.

At temperatures of around 20° C (68° F), water just sits there. Small amounts of water vapor evaporate from the surface, but nothing very significant. Unless you add perfume, that is: perfume evaporates even at 20° C, a feature that led to the success of your “Smell-Good Rose-Petal Washbasin™.”

If the temperature rises, more and more water vapor evaporates. The increase is dramatic: even small increases in temperature can dramatically increase evaporation rates. You used this fact in your hot-air blowing auto-dry towel-free shower, a best-seller in Japan.

When the temperature rises above 100° C (212° F), of course (or slightly higher temperatures if the pressure is higher than that at sea-level on Earth), water will boil, and will all turn into vapor. Water vapor is normally stable: it lasts forever, as long as the temperature remains high. Unless it is exposed to strong ultra-violet (UV) light, that is. The one blemish on your otherwise brilliant research career was the combined Jacuzzi and sunbed you produced a few years back: as the water vapor steamed off the surface of the water, the UV light from the tanning lamps (designed to mimic the healthy rays from the Sun) broke it down into hydrogen and oxygen. The oxygen would make people euphoric and sleepy, while the hydrogen built up until any spark (say from the off switch) caused it to explode. Your company is still recovering from all the lawsuits….
You are experts on how the gases that make up Earth’s atmosphere behave. Much of what you do involves routine stuff connected with the very uncertain science of weather forecasting. By now, you are used to constantly being the butt of jokes about wrong predictions.

But you also get to spend some time thinking about the bigger picture. Things like: How did Earth get its atmosphere in the first place? How has it changed over time? What will happen to it in the distant future?

At parties, when people find out what you do, and after the usual “weather-man” jokes (sometimes you think that even the lawyers have it easier), they often ask you why Earth’s atmosphere doesn’t just get sucked off into space. After all, space is an almost perfect vacuum, and it seems reasonable that air molecules would end up just drifting away.

You point out to them that it is gravity that provides the answer. Just as a stone thrown up, or even a bullet shot straight upwards, will fall to the ground, the molecules in the air cannot leave the Earth unless they have very high velocities—in fact, what is known as the escape velocity.

But not all gases are equal. Some are much harder to hold onto than others. At normal room temperature, the oxygen molecules that are continually bombarding your skin are moving, on average, at about 460 meters per second (1000 miles per hour). Strange, but true—faster than a speeding bullet! But, if we had some hydrogen molecules mixed in with the air, they would be moving even faster—over 4 times as fast, on average. So less massive atoms and molecules move faster at any given temperature.

The escape velocity for Earth is about 11 kilometers per second. That for Venus is only slightly less—about 10 kilometers per second. Most atoms and molecules in the upper atmospheres of both planets never reach these velocities, so gravity can retain most of the atmosphere. But you know that there are always a few molecules or atoms going much faster than the average, and that once one reaches escape speed going in the right direction, it is gone forever. Very few of the heavier atoms or molecules will escape, but, if you had, say, both hydrogen and oxygen atoms, you know that far more of the hydrogen atoms would be likely to escape than the oxygen atoms.

But these processes would work about the same on Earth and on Venus, so you don’t really see what you can contribute to the discussion.