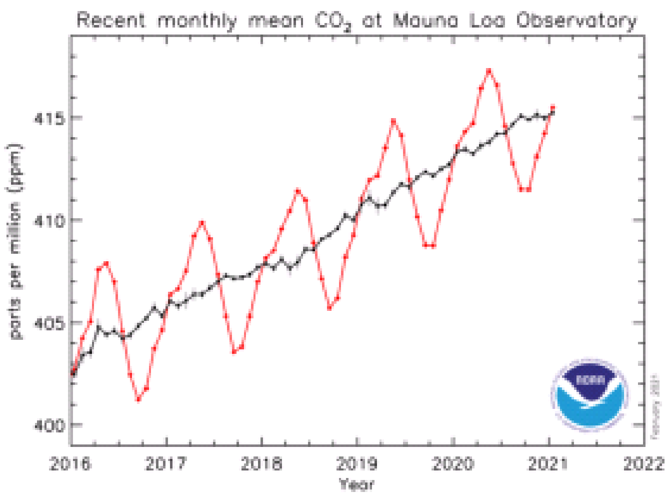
Welcome to the UT Regional 2021! This test is for Density Lab in Division B. You will have 50 minutes to complete this exam. Per TSO rules, you must use printed notes for this event. If you are communicating with your partner through voice or video call, please start it before you begin the test itself. Time spent out of the browser is grounds for penalty or disqualification.

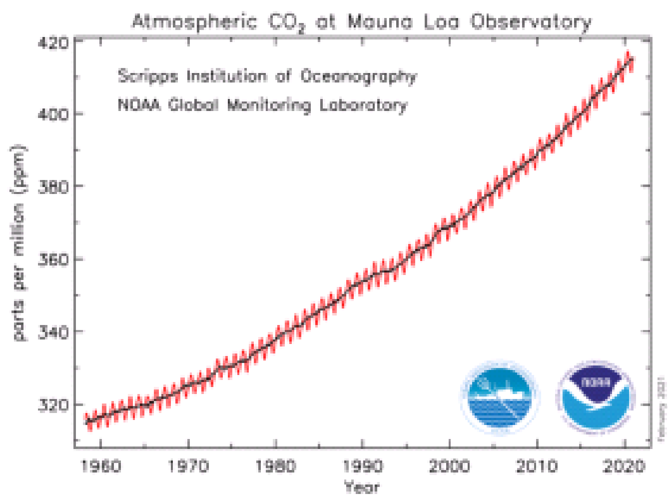
The questions in this exam will revolve around the theme of **climate change**. The science behind climate change is complicated, with competing effects and feedback loops galore, and to make these questions accessible to middle school students, we have to make a number of simplifications and assumptions (however, I had a climate researcher look through this exam to make sure these were reasonable!). Nevertheless, I hope that this exam will help you see the scientific basis for climate change and communicate the need for us to act quickly and decisively.

Good luck! And above all else, just believe.

Problem 1

Our journey begins in the beautiful state of Hawai'i, home of the Mauna Loa Observatory. Carbon dioxide is widely accepted to be one of the driving forces behind climate change, and since measurements started here in 1958, its concentration in our atmosphere has climbed from about 315 ppm to nearly 420 ppm, a mark that hasn't been seen in millions of years.





1. (1.00 pts) What does "ppm" stand for? *Hint: look at the y-axis of the graphs!*

parts | per | million

2. (1.00 pts)
The Mauna Loa Observatory is about 11,000 feet above sea level. In March, the high temperatures here are typically about 10 degrees Celsius, with a local barometric pressure of about 678 millibar.

To the nearest whole number, what is 10 degrees Celsius in Kelvin? Enter your answer as a whole number without any units or spaces.

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3. (2.00 pts) At these conditions, what is the molar volume, in mol/L, of the atmosphere surrounding the Mauna Loa Observatory? That is, find n/V using the Ideal Gas Law.

Expected Answer: n/V = P/RT = 0.0288 mol/L

4. (2.00 pts)
Mauna Loa reports their data as a dry air mole fraction defined as the number of molecules of carbon dioxide divided by the number of all molecules in air, including CO_2 itself, after water vapor has been removed. The mole fraction is expressed as parts per million (ppm). For example, a dry mole fraction of 0.000400 would be expressed as 400 ppm.

Suppose I magically isolated a cubic meter of the atmosphere surrounding the Mauna Loa Observatory on January 1, 2021 and counted all of the carbon dioxide molecules on that same day. How many would I find? In this question, assume that the amount of water in the atmosphere is negligible.

Expected Answer: Full credit for answers between 7.1e21 and 7.3e21 carbon dioxide molecules

5. (1.00 pts)
On their own, the measurements from the Mauna Loa Observatory cannot prove that the increase in carbon dioxide can be attributed to humans. One of the (many) ways scientists have been able to show that the increase in CO_2 is *caused* by humans is through analyzing the concentration of carbon isotopes in the atmosphere.

In your own words, briefly explain what an isotope is.

Expected Answer: Same number of protons, different number of neutrons

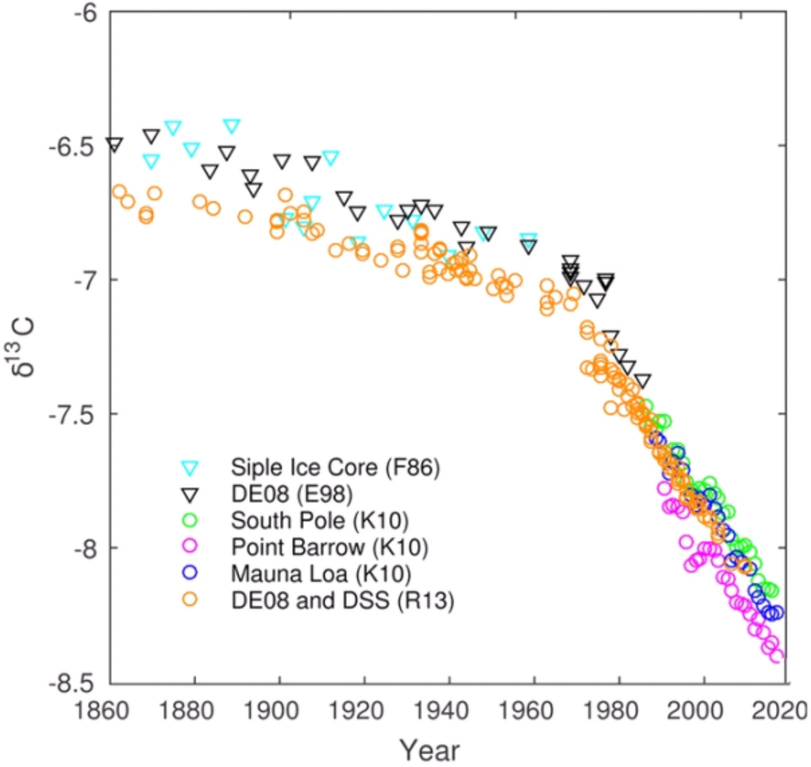
6. (2.00 pts)
On Earth, the two most common isotopes of carbon are Carbon-12 and Carbon-13. Plants let in gas molecules through small holes in their leaves called *stomata*. Generally, Carbon-13 is underrepresented in plants, as it's easier for plants to capture carbon dioxide molecules containing Carbon-12. This happens through diffusion. (Diffusion is the random movement of particles from an area of higher concentration to an area with a lower concentration of that particular particle).

Why might CO_2 containing Carbon-13 be worse at diffusing into stomata than CO2 containing Carbon-12? Frame your answer in terms of concepts in Density Lab, like speed, mass, and diffusivity.

Expected Answer: Full credit for saying that Carbon-12 is lighter than Carbon-13, so it will travel faster and selectively diffuse into the stomata.

7. (2.00 pts)
Although many people think of fossil fuels as "dead dinosaurs", scientists believe that most of the fossil fuel material we use today comes from ancient plants.

The ratio of Carbon-13 to Carbon-12 in our atmosphere has declined significantly since the start of the Industrial Revolution, when human use of fossil fuels began to increase significantly. This is one of the pieces of evidence scientists use to link rising concentrations of carbon dioxide to human activity. Why?



Expected Answer: Since fossil fuels are ultimately derived from ancient plants, plants and fossil fuels all have roughly the same Carbon-13/Carbon-12 ratio. As CO2 from these materials is released into, and mixes with, the atmosphere, the average Carbon-13/Carbon-12 ratio of the atmosphere decreases.

Problem 2

Water vapor, like carbon dioxide, is a greenhouse gas. The exact numbers vary on the specific model, but climate scientists estimate that water vapor (including water vapor in the form of clouds) accounts for 60-85% of the greenhouse effect, while carbon dioxide is only directly accountable for 10-30%. If that's the case, why do we care so much about carbon dioxide? The answer lies in how increases in carbon dioxide concentration impact the amount of water vapor in the atmosphere.

8. (3.00 pts)
Imagine a rigid box at room temperature, inside which is a complete vacuum. You magically put some liquid water, which is also at room temperature, inside the box, and notice that the molecules in the topmost layer of the water are evaporating. Why?

Expected Answer: At the microscopic level, the water molecules will have a range of kinetic energies, as described by a Maxwell-Boltzmann distribution. The molecules with the highest kinetic energies will be able to overcome the intermolecular forces of the molecules in the liquid, and escape as a gas. Alternatively, students can frame their answer in terms of a phase diagram/a substance wanting to be in vapor-liquid equilibrium.

9. (2.00 pts)
After some amount of time, the system reaches equilibrium; that is, the amount of liquid water and the pressure of the water vapor stay constant. Is this a static equilibrium or a dynamic equilibrium? Explain your answer.

Expected Answer: Dynamic. At equilibrium, the number of molecules entering and exiting the liquid phase will be the same.

10. (3.00 pts)
Suppose we increase the temperature of the box and allow it time to reach equilibrium again. Will the pressure of the water vapor increase or decrease? Explain your answer qualitatively.

Expected Answer: If the temperature is increased, them more molecules will be able to leave the liquid phase, which increases the amount of water vapor. Furthermore, the energy of the water molecules in the gas phase will be higher, so when they strike the surface of the liquid phase, it'll be harder for them to be "captured" and join the liquid phase.

11. (2.00 pts)
It turns out that the pressure of water vapor in our box at equilibrium is governed by the Clausius-Clapeyron equation. Many of its variables are temperature dependent, so applying this relation isn't easy. However, climate scientists have developed empirical approximations that provide extremely good estimates, like the August–Roche–Magnus formula,

$P(T) = 6.1094 \exp\left(\frac{17.625T}{T+243.04}\right)$

where $P(T)$ is the partial pressure of water in the atmosphere in hPa and T is the temperature in **Celsius (not Kelvin)**.

The average temperature of the Earth's atmosphere is 22.4°C. If we increase the temperature of the atmosphere by just 1°C, by what percent will the partial pressure of water vapor in the atmosphere increase?

Expected Answer: 6.2%

12. (2.00 pts)
Since 1988, satellites have determined that the average area density of atmospheric water vapor has increased by 0.41 kg/m^2. Given that the radius of the Earth is 6378 km, by how many more grams of water vapor are in the atmosphere today than in 1988?

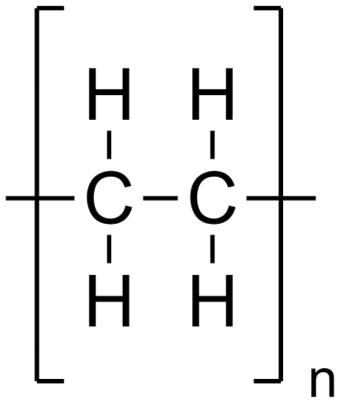
Expected Answer: 2×10^{17} grams

Our carbon emissions cause an increase in the temperature of our atmosphere, which increases the amount of water vapor in it. This water vapor goes on to heat the planet further, getting us stuck in an awful feedback loop. Without any feedbacks, a doubling of CO_2 would warm the globe around 1°C. Taken on its own, water vapour feedback roughly doubles the amount of CO_2 warming.

Problem 3

Although humans have used natural plastics (like rubber) for thousands of years, synthetic plastics (like polyethylene and polyvinyl chloride) only rose to prominence in the 1950s, thanks to some remarkable breakthroughs in chemistry and chemical engineering. From their relative strength and durability to their resistance to shock, corrosion, and harsh chemicals, plastics are in many ways, a wonder material.

13. (1.00 pts)
In the United States alone, we use over 50 billion plastic water bottles alone. These water bottles are typically made from a polymer called polyethylene, which is shown below.

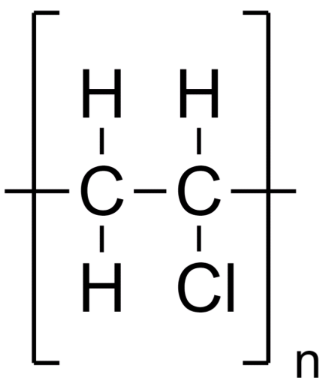


Which of the following intermolecular forces would you expect to be prevalent in polyethylene? Select all that apply.

(Mark **ALL** correct answers)

- [x] A) London dispersion forces
- [ ] B) Dipole-dipole forces
- [ ] C) Hydrogen bonding

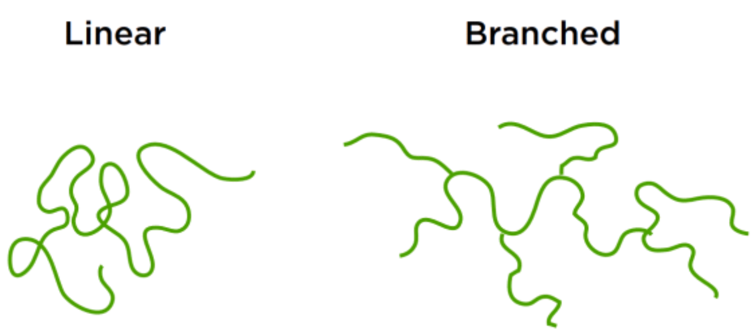
14. (2.00 pts)
Polyethylene is only one of the countless polymers out there. Another common polymer is polyvinyl chloride, or PVC. The structure of PVC is shown below.



Based on the structures of polyethylene and polyvinyl chloride, which one do you think is more dense? Explain your answer. *Note: Assume each monomer (the stuff between the brackets) is roughly the same volume.*

Expected Answer: PVC is more dense, Cl is a heavier atom than H.

15. (2.00 pts) Polymers aren't always linear chains - sometimes, they have branches, as shown below.



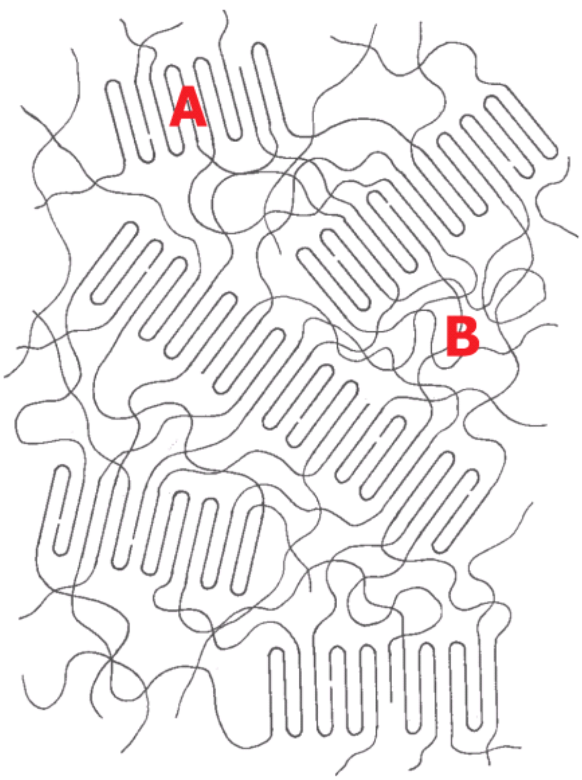
Consider two samples of polyethylene, one with branching and the other without. Which sample would you expect to have a lower density? Explain your answer.

Expected Answer: The sample with branching will have a lower density. The branches make it harder for each chain to fit together, so the branched chains will be spaced farther apart. (Essentially, m stays the same, but the branching causes V to go up, which in turn causes $\rho = m/V$ to go down.)

16. (2.00 pts)
Consider two samples of polyethylene: one low-density polyethylene (LDPE) and the other high-density polyethylene (HDPE). Which sample (LDPE or HDPE) would you expect to have a higher melting point? Explain your answer. *Hint: think about intermolecular forces.*

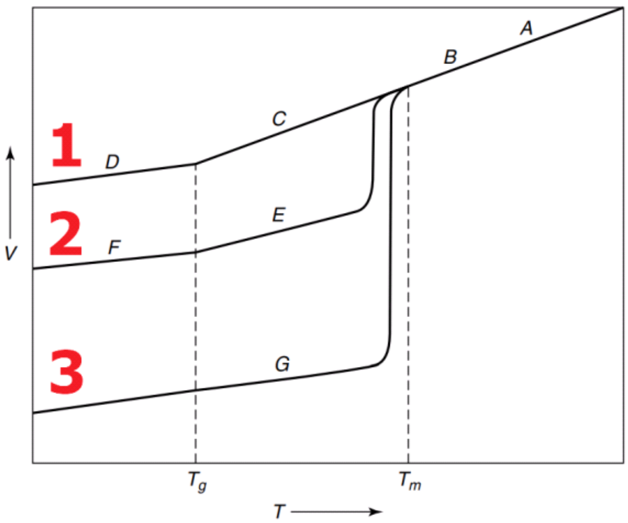
Expected Answer: HDPE would have the higher melting point. Higher density means the chains are packed more closely together, so the IMFs between chains will be stronger. As a result, it will take more energy to overcome those IMFs and melt the polymer.

17. (1.00 pts)
Polymers consist of both crystalline and amorphous areas. Crystalline areas consist of folded polymer chains that form ordered regions called lamellae, while amorphous areas are characterized by a lack of any repeating structure. In the diagram below, which letters correspond with which areas of the polymer?



- [x] A) A is crystalline, while B is amorphous
- [ ] B) A is amorphous, while B is crystalline

Consider the figure below, which shows temperature on the x-axis and specific volume (inverse density) on the y-axis. T_m refers to the melting temperature of the polymer.



18. (2.00 pts) Which branches (1-3) correspond with the polymer being completely amorphous, completely crystalline, or some mix of the two?

- ○ A) Branch 1: completely amorphous; Branch 2: completely crystalline; Branch 3: mixture
- ○ B) Branch 1: completely crystalline; Branch 2: completely amorphous; Branch 3: mixture
- ○ C) Branch 1: completely crystalline; Branch 2: mixture; Branch 3: completely amorphous
- ◉ D) Branch 1: completely amorphous; Branch 2: mixture; Branch 3: completely crystalline
- ○ E) Branch 1: mixture; Branch 2: completely crystalline; Branch 3: completely amorphous
- ○ F) Branch 1: mixture; Branch 2: completely amorphous; Branch 3: completely crystalline

19. (3.00 pts) Based the earlier descriptions of crystalline and amorphous areas, describe how the *cooling rate* of a polymer could affect how crystalline or amorphous it is.

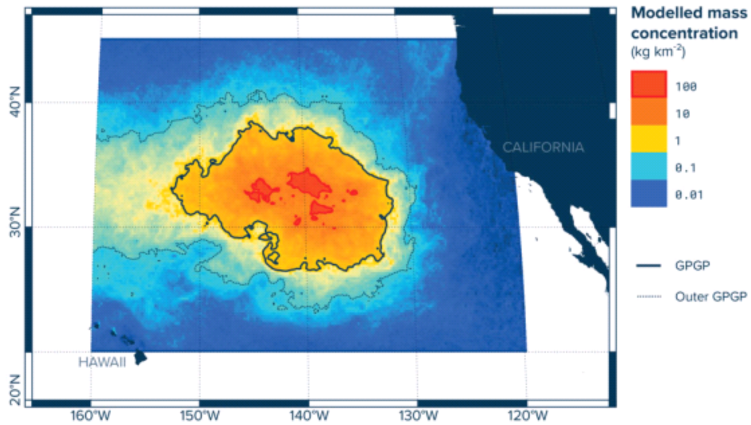
Expected Answer: Faster cooling -> less time for chains to arrange themselves into the ordered structure -> ends up being amorphous.

20. (3.00 pts)
Challenge: Now, let's put everything together. Suppose you have a solid sample of a polymer that starts at location C, but you would like it to be at location E. Explain how you could achieve this through melting and re-cooling the polymer. In your answer, be sure to include the *rate* at which you should re-cool the polymer.

Expected Answer: Melt it, then cool it slowly.

21. (3.00 pts)
One common misconception is that our usage of plastics is a significant contributor to climate change. While the carbon atoms in plastics often come from fossil fuels, producing plastic doesn't release a lot of carbon dioxide. Plastics are typically very durable, so their carbon is trapped in the backbone of the polymer and therefore can't easily escape as CO_2 and enter the atmosphere. This is in contrast with steel and cement, which both release an ungodly amount of carbon dioxide when they are made.

However, it also makes plastics excellent at polluting our planet, which is a very significant environmental problem that should not be neglected. One of the most famous examples of how significant plastic pollution has become is the Great Pacific Garbage Patch (GPGP), a collection of marine debris in the North Pacific Ocean. An map of the area density of plastic garbage in the GPGP is shown below:



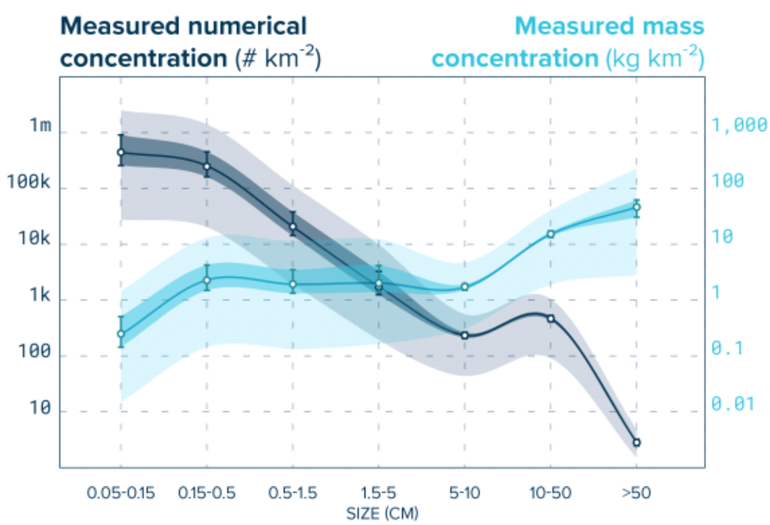
To the nearest power of 10, estimate the mass of all the plastic garbage in the GPGP (the area bounded by the solid black line, not the dotted line) in kg. Don't stress about being exact, just do your best to make reasonable assumptions and estimations.

The following information may be useful:

- Lines of longitude are vertical, while lines of latitude are horizontal (**lat**itutde is **flat**)
- Each degree of latitude corresponds to a physical distance of 110 km
- At 20°N, each degree of longitude corresponds to a physical distance of 104.14 km
- At 30°N, each degree of longitude corresponds to a physical distance of 96.2 km
- At 40°N, each degree of longitude corresponds to a physical distance of 85.1 km

Expected Answer: Full credit for 10^8, 10^7, or 10^6 kg if students' assumptions and work are reasonable.

22. (1.00 pts)



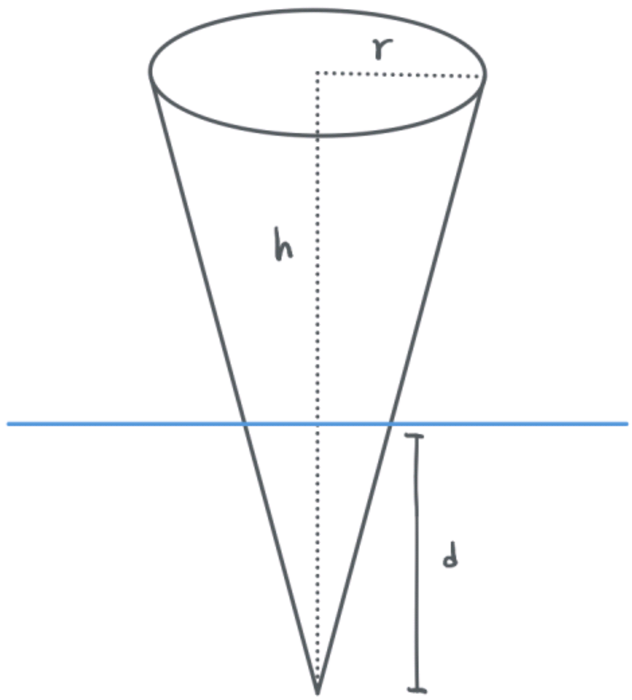
The chart above shows the how different sizes of debris contribute to the numerical and mass area densities of the GPGP. Based on this data, which of the following statements is correct?

- ○ A) A majority of the debris is small, and small pieces of debris comprise most of the mass in the GPGP.
- ○ B) A majority of the debris is large, and large pieces of debris comprise most of the mass in the GPGP.
- ◉ C) A majority of the debris is small, but large pieces of debris comprise most of the mass in the GPGP.
- ○ D) A majority of the debris is large, but small pieces of debris comprise most of the mass in the GPGP.
- ○ E) None of the above

Problem 4

Our journey takes us from the Pacific Ocean to the Arctic, where climate change is resulting in significant loss of sea ice.

Consider a conical piece of sea ice of radius r, height h, and density ρ_i floating in seawater of density ρ_w.



23. (1.00 pts) What fraction of the sea ice's volume will be *below* the surface of the water?

Expected Answer: ρ_i/ρ_w

24. (4.00 pts) Find an expression for d, the depth of the sea ice under the surface of the water, in terms of ρ_i, ρ_w, and h.

Expected Answer: $d = h(\rho_i/\rho_w)^{1/3}$

25. (6.00 pts)
Polar bears rely on sea ice to hunt and rest. Rising temperatures cause the sea ice to melt earlier in the year, driving the bears to shore before they have built sufficient fat reserves to survive the period of scarce food in the late summer and early fall, leading to malnutrition or starvation.

Suppose a polar bear of mass M climbs on top of our piece of sea ice. Find a new expression for d, the depth of the sea ice under the surface of the water, in terms of ρ_i, ρ_w, h, M, and π.

Expected Answer: $d = \left(h^3\frac{\rho_i}{\rho_w} + \frac{3Mh^2}{\pi r^2 \rho_w}\right)^{1/3}$

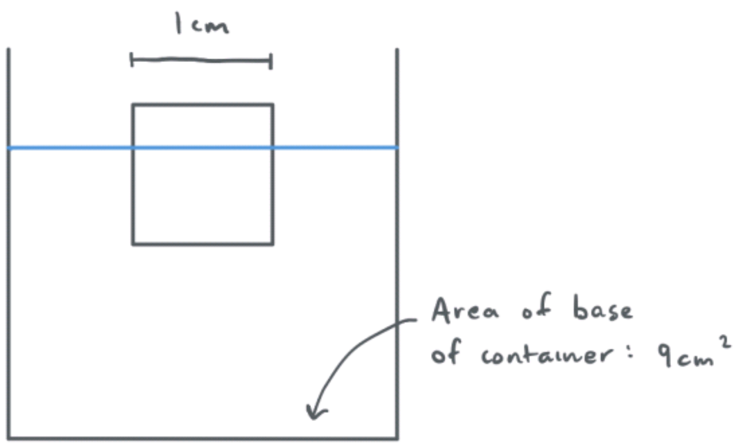
Problem 5

One of the effects of climate change is sea level rise. What causes sea level rise?

Suppose you're interested in the effect melting sea ice may have on sea levels, which have risen steadily over the past century. You construct a simple experiment, which is described below:

- **Scenario 1**: Pure ice of density 0.92 g/cm^3 melts into pure water of density 1.000 g/cm^3
- **Scenario 2:** Pure ice of density 0.92 g/cm^3 melts into salt water of density 1.029 g/cm^3

In each scenario, the ice is a cube of side length 1 cm, and the area of the container is 9 cm^2. The ice is already floating in the water at the start of the experiment.



26. (1.00 pts)
Most of the ions in the ocean are Na^+ and Cl^-, so you decide to create your salt water solutions using NaCl. Assuming that the change in volume of the solution is negligible when you add the NaCl, how many moles should you add to reach a density of 1.029 g/cm^3? The solution has a volume of 90 mL.

Hint: the molar mass of NaCl is 58.44 g/mol

Expected Answer: 0.045 moles NaCl

27. (1.00 pts) What is the concentration of the salt water solution, in g/mL?

Expected Answer: 2.61 g/90 mL = 0.029 g/mL

28. (2.00 pts) In Scenario 1, by how much has the water level risen after the ice cube has completely melted? Give your answer in centimeters.

Expected Answer: 0 cm (the water level does not change)

29. (3.00 pts) In Scenario 2, by how much has the water level risen after the ice cube has completely melted? Give your answer in centimeters.

Expected Answer: Volume of water displaced: 0.894 cm3 1 cm3 of ice melts to form 0.92 cm3 of fresh water The change in water level is 0.0029 cm

30. (2.00 pts)
When sea ice forms, most of the salt is pushed into the ocean water below the ice, although some salt gets trapped in small pockets between ice crystals. Overall, the salinity of sea ice typically ends up being about 30% that of seawater.

During our experiment, we assumed that the sea ice was pure. Suppose that in Scenario 2, we modeled our sea ice as a "salty" ice cube that has a higher density than pure ice. Would this cause our observed rise in the water level to increase, decrease, or stay the same? Explain your answer!

Expected Answer: The increase in the water level would decrease.

31. (3.00 pts)
Now, you get curious about the effect of melting land ice (e.g. glacier) on sea level rise. You run another experiment, using the same container (area of 9 cm^2) and ice cube size (side length of 1 cm), in which you let the ice cube melt completely and then transfer the pure water to the container, which contains saltwater. By how much does the water level in the container rise? Here, assume that the mixture of freshwater and saltwater is an ideal solution, so volumes are additive.

Expected Answer: 0.92 cm3/9 cm2 = 0.10 cm

32. (1.00 pts) Based on your findings, which of the following do you think affects sea level rise more?

- ○ A) Melting sea ice
- ● B) Melting land ice

In addition to melting ice, the thermal expansion of sea water also contributes to sea level rise. Essentially, heating up water causes it to expand.

In the United States, almost 40 percent of the population lives in relatively high population-density coastal areas, where sea level plays a role in flooding, shoreline erosion, and hazards from storms. Globally, 8 of the world's 10 largest cities are near a coast, according to the U.N. Atlas of the Oceans.

Problem 6

Electricity usage accounts for 27% of the 51 billion tons of greenhouse gases we emit each year. As a result, figuring out how to power our lives in a manner that minimizes our greenhouse gas emissions is paramount to ameliorating the effects of climate change. In this problem, we'll take a closer look at silicon, one of the most widely-used materials to make photovoltaic cells.

33. (1.00 pts)
At the beginning of a semiconductor manufacturing process, our purified silicon is in the form of a cylindrical ingot. Today, some of the largest ingots used commercially have a diameter of 30 centimeters and are 2 meters long. What would the mass, in kilograms, be of such an ingot? *Note: the density of silicon is 2.33 g/cm^3.*

Expected Answer: m = rho * volume = (2330 kg/m3)*(0.15m^2)*pi*(2m) = 329 kg

34. (2.00 pts)
What is the number density, in cm^{-3}, of silicon atoms in our ingot? *Hint: you don't need the volume; start with the density, divide by the molar mass of silicon, and go from there!*

Expected Answer: 5×10^{22} atoms/cm3

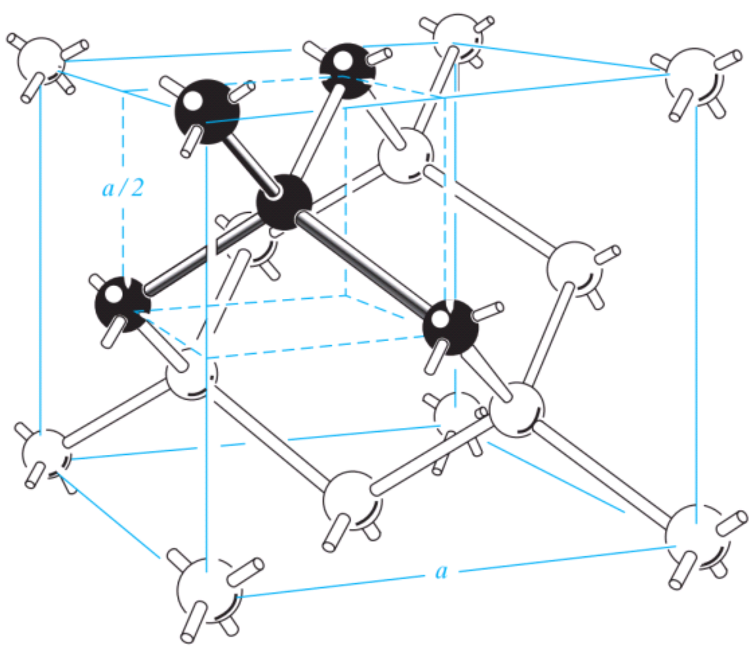
35. (1.00 pts)
After the ingot of purified silicon is produced, engineers slice thin "wafer" using a specialized wire saw. Typically, solar cells made of crystalline silicon are made from wafers between 160 and 240 micrometers thick.

How many silicon atoms would be in a wafer 200 micrometers thick from our 30-cm diameter ingot?

Expected Answer: 1.18e24 atoms

36. (4.00 pts)
In our wafer, the silicon atoms will be arranged in a specific *crystal structure*, which is determined by the atoms' size and bonding. Below is an illustration of the "unit cell" of pure silicon; putting many of these unit cells next to each other would create the entire solid. In this illustration, the silicon atoms are drawn as small spheres to make the bonds clearer, but usually, scientists approximate them as hard sphere that touch each other. Given that the lattice parameter, a is 0.543 nm, what is the radius of each silicon atom if we approximate them as hard spheres?

Note: this problem is on the harder side for Division B students, and requires some creative geometry and visualization. Don't spend too much time on this question if you haven't finished the exam!



Expected Answer: 0.118 nm

37. (1.00 pts)
Some power sources take up more space than others. Obviously, space is far from the only constraint when trying to shift to alternative energy sources, but it is still an important consideration. The relevant metric here is the *power density* of each energy source. It tells you how much power you can get from a source of energy per unit area of land (often measured in Watts per square meter).

In order to power the United States, we'd need about 10^{12} Watts. Suppose we try to cover this energy demand only with solar power, which has an energy density of 20 W/m^2. What area of solar panels would we need, in m^2?

Expected Answer: 5×10^{10} square meters

38. (1.00 pts)
Nuclear energy, on the other hand, has an energy density of about 1000 W/m^2. Let L_n be the area of land needed if nuclear energy alone fulfilled our energy needs, and L_s the area of land needed if solar power alone fulfilled our energy needs. What is L_s/L_n?

Expected Answer: 50

This doesn't mean one form of alternative energy is inherently better than another. It just means that they have different land requirements, which need to be taken into account when determining how we can transition our energy grid to something more sustainable. Fossil fuels are ubiquitous for a reason - they're easy to transport, reliable, and have an incredibly high energy density (up to 10^4 W/m^2). It's unlikely that any one source of alternative energy could replace fossil fuels on its own. Instead, it'll probably have to be a team effort.

Problem 7

Some people argue that colonizing another planet is easier than trying to fight climate change. They are probably wrong.

Mars has a thin, tenuous atmosphere. Here are some facts about it:

- Average temperature: 210 K
- Average surface pressure: 610 Pa
- Scale height: 11.1 km
- Composition: Carbon Dioxide (CO_2) - 95.1%; Nitrogen (N_2) - 2.59%; Argon (Ar) - 1.94%

39. (2.00 pts)
The radius of Mars is 3380 km, which is much greater than its atmosphere's scale height. In situations like these, the volume of a thin spherical shell can be approximated by the following equation:

$V = 4\pi R^2 \Delta H$, where $\Delta H << R$.

Using this equation, estimate the volume of the atmosphere of Mars in cubic meters.

Note: In truth, estimating the "volume" of an atmosphere is difficult since an atmosphere doesn't have a clearly defined edge. However, for the purposes of this question, using the scale height of the atmosphere is reasonable and gives a value that is accurate enough.

Expected Answer: 5.55×10^{17} cubic meters

40. (3.00 pts)
Since the vast majority of Mars's atmosphere is carbon dioxide, the average molar mass of the molecules in its atmosphere will be almost exactly the same as the molar mass of carbon dioxide, which is 44 g/mol. Estimate the mass of the atmosphere of Mars, in kg, using the Ideal Gas Law.

Expected Answer: 2.444×10^{16} kg

41. (3.00 pts)

Since the average surface pressure on Mars is so low, using the Ideal Gas Law is a reasonable approximation. In a couple of sentences, explain why gases behave more ideally at lower pressures.

Expected Answer: At low pressures, molecules in the gas will travel extremely far distances between collisions. Since encounters between gas molecules at low pressure are relatively rare, the molecular structure of a gas (i.e. types of chemical bonds, size, mass, etc.) has no influence on its behavior under this condition.

In order to warm up Mars, we need a thicker atmosphere that contains greenhouse gases. The most accessible stores of carbon dioxide on Mars lie at its poles, particularly at the South Polar Ice Cap. There, the solid carbon dioxide (also known as dry ice) could theoretically be heated, causing it to sublimate.

Using SHARAD (shallow radar) data from the Mars Reconnaissance Orbiter, Phillips et. al. estimate that the buried carbon dioxide deposits within the south polar layered deposits of Mars have a volume of 12500 cubic kilometers and a bulk density of 1500 kg/m^3.

42. (2.00 pts) Assuming that the dry ice deposits are pure carbon dioxide, how many moles of CO_2 are in the deposit?

Expected Answer: 4.26×10^{17} mol

43. (1.00 pts)
The amount of energy needed for dry ice to sublimate (i.e., its enthalpy of sublimation) is about 26 kJ/mol. How much energy would it take for all of the dry ice to sublimate, in Joules?

Hint: multiply your answer to the previous question by 26, and then convert your answer from kJ to J

Expected Answer: 1.1×10^{22} Joules

44. (3.00 pts)
Suppose all of this carbon dioxide were to sublimate and join the Martian atmosphere, causing the scale height of the atmosphere to increase by 10%. What is the new pressure on Mars, in atm?

Expected Answer: 0.01213 atm

Even if we do all that work, scientists estimate that the resulting greenhouse effect would only increase the temperature on Mars by a very small amount, roughly on the order of 10 Kelvin, which isn't nearly enough. The other possible sources of carbon are either too small or completely inaccessible. Terraforming Mars is not feasible on a reasonable timescale with our current technology.

As a result, some people set their sights beyond the Solar System, hoping a nearby exoplanet could be their savior. In the next part of this question, we'll explore how astronomers determine the density of an exoplanet, which helps them narrow down its composition.

45. (1.00 pts)
When a planet orbits a star, it also causes the star to wobble due to the gravitational pull between them. The larger the mass of the planet, the bigger these wobbles will be. By measuring these wobbles very closely, we can determine both the mass of the plant and how long it takes to orbit its star. This is called the *radial velocity method* for discovering exoplanets.

Consider two planets, A and B, that both orbit identical stars at the same distance. Both planets are the same size, but A is more dense than B. Which planet will cause its host star to have larger wobbles? Explain your answer.

Hint: Which planet will have the larger mass?

Expected Answer: Both are the same size, but A is denser, so A will also be more massive. A will have a larger gravitational pull on its host star, causing that star to wobble more.

46. (2.00 pts)
Scientists can estimate the radius of a planet by measuring its *transits*. Essentially, the planet passes in front of the star, causing the star to look dimmer since the planet is blocking some of the light. The larger the planet, the more light it blocks, and the dimmer the star appears, as shown in the relation below:

$\Delta B = (R_p/R_s)^2$

where ΔB is the change in the star's brightness, R_p is the radius of the planet, and R_s is the radius of the star.

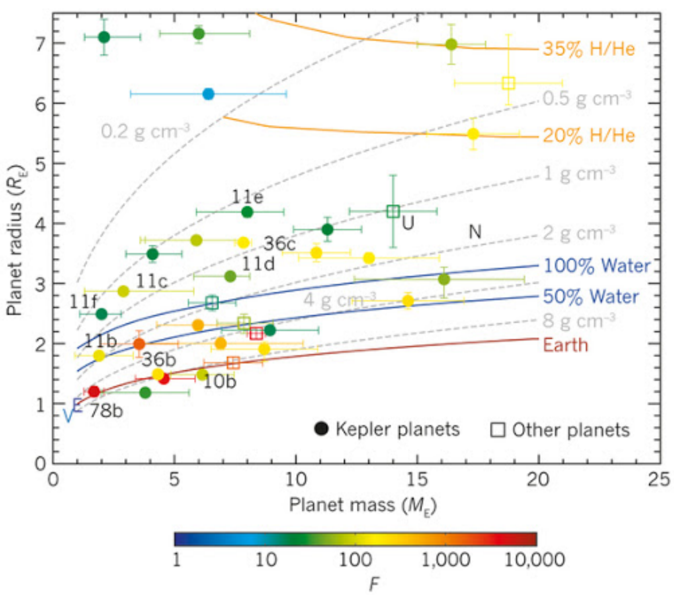
Suppose an exoplanet transits a star of radius of 3.64×10^5 km, resulting in ΔB = 0.00042. What is the radius of the planet, in kilometers?

Expected Answer: 7450 km

47. (2.00 pts)
Using the radial velocity method, scientists determine that the mass of our exoplanet from the previous question is 8.36×10^{24} kg, or 1.4 Earth masses. What is the density of this exoplanet, in kg/m^3? Use the radius you calculated in the previous question.

Expected Answer: 4827 kg/m3

48. (3.00 pts)
Scientists use plots like these to evaluate possible compositions of a planet based on their mass and radius. Based on the mass and radius values for our exoplanet, roughly estimate its composition. I'm not looking for anything specific - saying something like "20% H/He" or "between 100% and 50% water" is perfect. If you weren't able to calculate the radius of the exoplanet, explain *how* you would use this diagram to determine its composition.



Hint: 1 Earth radius is about 6370 km

Expected Answer: Earth-like

All of this is fine and dandy, but we'd actually want to get to this planet. The nearest star to our Solar System is 4.23 light years (4×10^{13} km) from Earth. The fastest spacecraft speed was achieved by the Parker Solar Probe, which hit 466,592 km/h at its nearest approach to the Sun. Even at that colossal speed, it would take 10^4 YEARS just to reach the nearest star system, and most planets will be much further away.

The message of this question is clear: escaping the reality of climate change on Earth by going somewhere else is difficult, if not downright impossible with our current technology. Instead of trying to avoid the problem, we need to have the courage to face it head-on.

Climate change is complicated - too complicated for one Science Olympiad exam meant for middle schoolers to truly cover everything. Unfortunately, this complexity has led to discussions about climate change becoming needlessly political, with people (including our senators, Ted Cruz and John Cornyn) denying the existence of anthropogenic climate change, even against the broad scientific consensus. It's true that we don't know everything about climate change, but we know enough to see the trend and not bet against the house.

There is no simple solution to climate change. Instead of "debating" about whether it exists, we should be working together to combat it. Our generation will bear the brunt of the effects of climate change, and it is up to us to fight to ameliorate them. It won't be easy, but I am optimistic that we can make a difference if we believe in ourselves.

If you have any feedback about any of the exams at this tournament, please let us know through this form: https://tinyurl.com/utreg21feedback (https://tinyurl.com/utreg21feedback)