SOME THINGS ARE CONSERVED – CONTINUATION

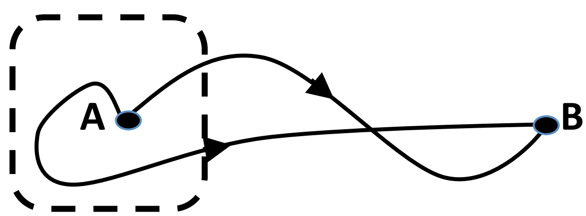
Directions: Read the text and answer the questions on a **separate sheet of paper**.

III. Local Conservation Rules and Other Possibilities

You should've come up with something like these rules for conservation. These are the two rules something has to follow to be conserved, in a very special way: locally. **If the universe conserves something, the thing is ALWAYS conserved locally**:

A. That "stuff" can't just appear or disappear. To be conserved in a certain interval of time, the stuff must continue to BE, throughout, to say it is conserved. For example, while water stays water, that's fine. If something happens to make water no longer water (say a chemical reaction occurs), it stops being conserved. This is what it takes to be conserved, locally or not.

B. In order to get from point A to point B, "stuff" has to follow some continuous path, ANY path between those two points. It can't randomly jump from A to B without passing through the space between. See the diagram below. This is the local part. Something isn't local if it can just teleport instantly from place to place.



Global Conservation – the Universe NEVER does this

Suppose for a second that the universe did conserve something (rule A), but it did NOT do it locally (rule B). We might call this "global" conservation. If things were conserved globally, not locally, our life would be VERY DIFFERENT! Let's use water as our example, again. If water is globally conserved, not locally conserved, that would mean the total amount of water in the entire universe is always the same, but it could move around however it wanted. It obeys rule (A) but it breaks (B). It wouldn't have to pass through the top of the tank in order to build up inside it. It could disappear and reappear at any time. Water from Mars could randomly materialize above your lap during a job interview. Thankfully, that's not how the universe works. In fact, we intuitively understand that's how things work. We depend on it, which is why global conservation would feel so weird if the universe worked that way.

No Conservation: some things, some of the time, are not conserved

The other alternative to local conservation is that something isn't conserved, at all. This means that some of the time, that thing breaks both rule (A) and rule (B). Well believe it or not, this IS how the universe works for a lot of things, including water. But usually this is only true some of the time. **Most of the time, things are conserved,**

and when they are, they're always conserved locally. And when they aren't, it's not quite as weird as you might think, for this reason: if something breaks rule (A) and disappears, then we don't have to worry about it randomly jumping around (breaking rule B) because it doesn't exist anymore. So, if water turns reacts with something and turns into another chemical, that water doesn't exist anymore (but whatever it turned into just popped into existence). See, it's not so bad. The real difficulty is challenging your idea of a "thing". There are plenty of other things the universe doesn't conserve. Humans are one of them.

1. In the first two questions, we saw that **some of the time** humans are locally conserved. So, they sometimes obey the equations on the first page for conservation of humans, which means they also sometimes obey rule A and rule B. But that's not true **all of the time**, and we want to know how the universe **always** works. Think of 2 examples of when humans are not conserved.
2. Think of another example of something other than humans or molecules like water that the universe does NOT conserve, and explain thoroughly how you know.

IV. What IS and IS NOT Conserved

Water and other Molecules

I already mentioned water isn't conserved during a chemical reaction. Here it is in a little more depth. We all know water is made of 2 Hydrogen atoms bonded to 1 Oxygen atom to form H_2O. Say at some point in time, we have water and sodium (Na) inside of our tank and nothing escapes. Here is the reaction:

$$\mathbf{2Na + 2H_2O \dashrightarrow 2NaOH + H_2}$$

Before the reaction you have 2 moles of water and 2 moles of Na. After the reaction, you have no water and no Na (though you have some other stuff). When the reaction starts, we are violating rule (A) of local conservation: stuff cannot appear or disappear and still be called "conserved". All molecules can undergo chemical reactions, so the universe doesn't conserve water, or any other molecule (at least not all the time).

Atoms

How about atoms? Atoms are conserved normally. It's atoms that make up people and we were conserved in our activity from the first page. Atoms make up nearly everything around us. This leads to the observation: "You can't clean something without making something else dirty." If you've taken chemistry, you know that atoms are even conserved during a chemical reaction, and you can see it in the reaction, above. Molecules turn into other molecules but the atoms just move around and become bound to other atoms. Those atoms don't ever disappear or reappear (property A) and they move through space without smoothly through space (property B). So even during a chemical reaction, atoms are locally conserved. But are atoms conserved all the time? If atoms are not conserved all of the time, all we need is one example where they violate one of our rules.

3. Google "radioactive decay of Carbon-14". Are atoms always conserved? If they are not, which rule to they break?

Charge

Let's think a little more abstractly about what we call a "thing". How about charge? Is charge conserved? The electrons remain stuck to an atom because all fundamental particles like electrons have this property called **charge**, which is what causes the **electric force**. Charged particles are building up in your phone's battery while it is **charging.** Charge is measured in Coulombs (C), and can be positive or negative (or zero). Charges with the same sign repel. Charges with opposite sign attract. So…is charge conserved? We will see much more of this, but the answer is YES charge is ALWAYS conserved! And it's conserved locally, too!

Mass

What about **mass**? We are used to mass, but what we probably don't know is that mass is similar to charge, in some respects. Charge is the property of matter that causes the electric force. Mass is the property of matter that causes the **gravitational force**. Charge is measured in Coulombs (C), and can be positive or negative, so it can attract and repel. Mass is measured in kilograms (kg), and is never negative so two objects with mass always attract each other. They never repel.

Charge is conserved. Is mass conserved? The answer, it turns out, is no. Most of the time this is approximately true, but sometimes this definitely isn't. All fundamental particles have a look-alike particle called an **antiparticle** (If particles make up **matter**, antiparticles make up **antimatter** – antimatter is rare). The electron's antiparticle is called an antielectron, or more often a positron. The positron has the same mass as an electron and equal but opposite sign for charge (so together they have zero charge). If the positron and electron get near each other they "annihilate". They both disappear and become a **photon**, the particle that makes up light. Electrons and positrons have mass but photons have zero mass (and zero charge).

4. Google "electron positron annihilation". Then answer which rule of local conservation is broken during this process, arguing that mass is not conserved?
5. If nothing beyond the electron, positron, and the photon produced are involved in the reaction:
    a. Find the values for each term in the conservation of charge equation on the first page: **Charge Inside (initial) = ?, (Charge that Flowed In – Charge that Flowed Out) = ?, Charge Inside (final) = ?**
    b. Discuss how charge satisfies the two rules of local conservation in this process.

Energy

So mass is not always conserved because some mass went away in particle-antiparticle annihilation. What doesn't go away is **energy**. Energy is the most important thing the universe conserves that you'll ever come across! This is what we'll be spending much of our time with. Energy has different types that it can transform to or from. In this case, the electron's and positron's **mass energy** and **kinetic energy** turn into the **electromagnetic energy** of the emitted light.

<u>V. For the Future</u>

The universe conserves some weirder things, too, such as **momentum** and **angular momentum**. The momentum of an object, is the product of the object's mass and its velocity: **m*v**. The **total force** from things outside the system is what transfers momentum into or out of the system. If momentum flows in, the amount of momentum in the system increases. For example, if the momentum increases, you might see the object speed up. If momentum flows out, momentum in the system decreases. You might then see the object slow down. Angular momentum is similar but objects rotate rather than move in a straight line. The **total torque** from objects outside the system is what transfers angular momentum into or out of the system. Both of these match our conservation of "stuff" equation:

Momentum Inside (Initial) + (Momentum that Flowed In – Momentum that Flowed Out) = Momentum Inside (Final)

Next to energy, forces are the second most important concept in physics!

6. Create a table with the heading below and fill it in with the examples mentioned.

Stuff the Universe Conserves All of the Time	Stuff the Universe Does NOT Conserve All of the Time