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Why?

I plan on doing theoretical physics research as a career once I finish school. Occasionally, people I have told this to have suggested that, as a field, it is not useful for society. From what I have been able to gather from these people, theoretical physics seems too abstract to them and too distant from their everyday life to have any real impact. They’re wrong. The ideas that most readily come to mind when thinking about theoretic physics research are those such as general relativity, quantum mechanics, and string theory. Currently, we do not have enough of a grasp of string theory to make use of it, and in fact, we do not even know if it is the correct line of inquiry, but the other two are used in things that the average American interacts with daily. There is even one such application that they are used in together: GPS satellites!

The theory of general relativity predicts that objects that are closer to the center of a gravity well (the distortion of space-time caused by mass) will experience time at a slower rate than those that are further from the center. This effect also depends on the mass of the object, causing the gravitational distortion. Similarly, objects will experience time at a slower rate if they are traveling at a speed that is closer to the speed of light. GPS satellites rely on our understanding of these effects because they determine position by sending signals from three positions to a receiver and using the time the signal traveled with the speed of light to determine the distance from each satellite to the receiver. Once these distances are determined, the system uses trigonometry to calculate the position of the receiver.

This system clearly relies on very precise measurements of time because very little time is taken for the light to travel between the satellites and the receiver. These timings must be correct to within 20 nanoseconds, or seconds. If we were not able to correct for the difference in the passage of time due to relativity, the clocks on GPS satellites would be ahead of the clocks on earth by an additional 38 microseconds, or 38,000 nanoseconds per day. This discrepancy would result in a very incorrect position after only two minutes, and this imprecision would continue to add up at a rate of ten kilometers per day.

No normal clock could possibly match the 20 nanosecond precision required for the GPS to function. In many modern clocks, a quartz oscillator is used to keep time. These oscillators implement the fact that quartz resonates at a particular frequency when an electric current is applied. This vibration is used like a pendulum in a grandfather clock. Instead of clocks based on quartz, GPS satellites are equipped with atomic clocks which keep time by monitoring the resonant frequency of atoms of a particular element. Atoms are composed of a nucleus that is surrounded by electrons. These electrons and be in various states known as energy levels and can be made to jump between energy levels if electromagnetic radiation of a particular frequency is applied. If the frequency is accurate, a large number of atoms will have electrons which change energy levels. If the frequency is not accurate, fewer atoms will have electrons that change states, and the frequency will be adjusted to bring it closer to the accurate frequency. As this process continues, the frequency will be used to track the passage of time by counting the cycles of the electromagnetic waves.

General relativity and quantum mechanics are two fields of study that are among the most abstract and seemingly far removed from everyday life, but even these are used in more than just GPS satellites. Additionally, if we were not to research topics that had no known use, we would progress far more slowly. General relativity and quantum mechanics were both initially developed almost 80 years before the GPS first became operational, and none of the pioneers of these fields could have anticipated the uses we would find for them, which goes to show that to limit ourselves in such a way would be incredibly foolish.