No: 29

1 January 2021

JoSS

Joy of Sharing Science

An Independent Initiative of Uskudar American Academy Volunteer Students

Editor: Fazıl Onuralp Ardıç

Joy of Sharing Science 2020

This newspaper is an independent initiative of Uskudar American Academy volunteer students.

The Joy of Sharing Science is a weekly newspaper that explores the physics/biology/chemistry behind interesting real-life phenomena in a concise and easily understandable way. Each week, 3 phenomena concerning physics, chemistry, and biology will be published. The aim of this project is to explore the science hidden in plain sight, evoke curiosity, and elevate scientific literacy.

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From the Editor:

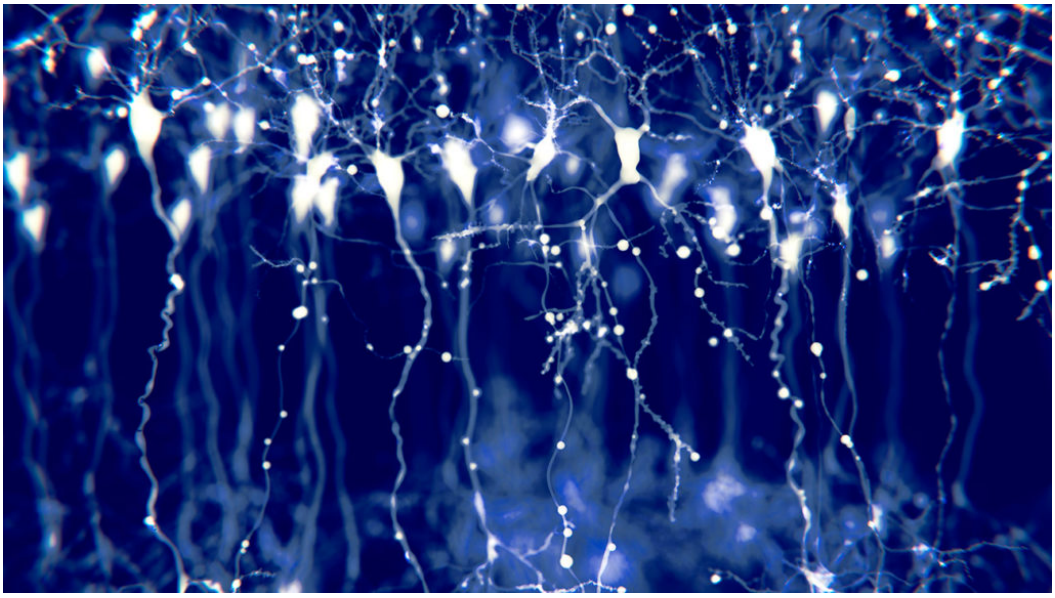
In this issue, our topics range from neuroplasticity and methamphetamine to two possible theories for quantum gravity.

To start with, our biology author Ceylin Gün investigates how our brain structures change over time (for the better or worse) and which factors play a major role in this plasticity. After her, our chemistry author Eylül Ustaoğlu inspects various mechanisms which have been used for manufacturing methamphetamine. Finally, in a collaboration article, our physics authors Elif Ilgın Özdemir and Hüseyin Yağız Devre look into two possible theories reconciling General Relativity and Quantum Mechanics after providing appropriate background knowledge.

Always stay curious and enjoy!

Fazıl Onuralp Arduç

The Ever-changing Brain



Ceylin Gün

At the end of the day when you are ready to sleep in your bed, you have a different brain than the one you woke up with that morning. You have new memories, you learned new knowledge, and you gained new experiences. They all have biological correspondence in your brain; when you finish this article, you will have a different brain than the one at this exact point, because you will, hopefully, learn new information about neuroplasticity, and that information will be stored in your brain.

Neuroplasticity is the ability of the brain to reorganize itself in response to experience. It used to be a common view that the brain could only change its organization within the early stages of neurodevelopment, which includes the embryonic stage. After that, scientists thought that the brain maintained its structure pretty much the same for the rest of a person's life. Today, it is known that the brain changes depending on numerous factors, and its change can be even manipulated by controlling sensory inputs. Marian Diamond established one of the paradigm-shifts in neuroscience by proposing that the brain shrinks with malnourishment and poor conditions, and it actually grows by size in an enriched environment regardless of age.

There are two types of neuroplasticity: functional and structural plasticity. Functional plasticity is the ability of the brain to carry the functions from a damaged area to an undamaged area. For example, if a right-handed tennis player has a stroke that debilitates the area of her brain that controls the motor functions for her right arm, she will not be able to use her right arm for playing tennis immediately after the stroke. She will be given small tasks to complete with her right hand such as cleaning a table. With practice, she will form new synapses that will allow her to use her right arm again, but that synaptic formations will not be in the damaged area, but an undamaged area. Another type of plasticity is called structural plasticity. Physical structure of the brain will alter as a result of new experiences.

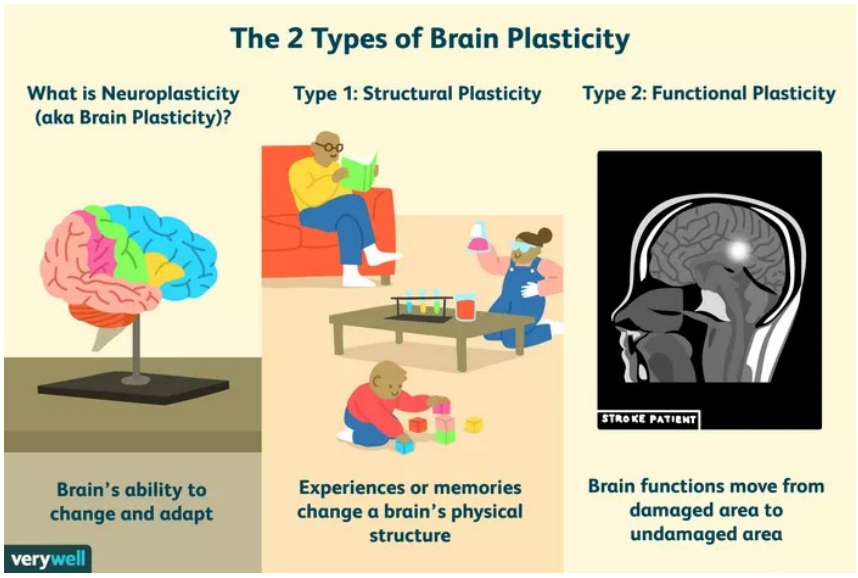


Figure 1: Types of Brain Plasticity

It is often said that neuroplasticity has two pathways of functioning. One is rerouting and the other one is sprouting. Rerouting establishes alternate pathways for a severed previously existing pathway. Sprouting refers to the sprouting ability of axons. A branch from the axon of a neuron may sprout to form a new synapse with a different neuron than the one with which the original axon terminal was forming a synapse.

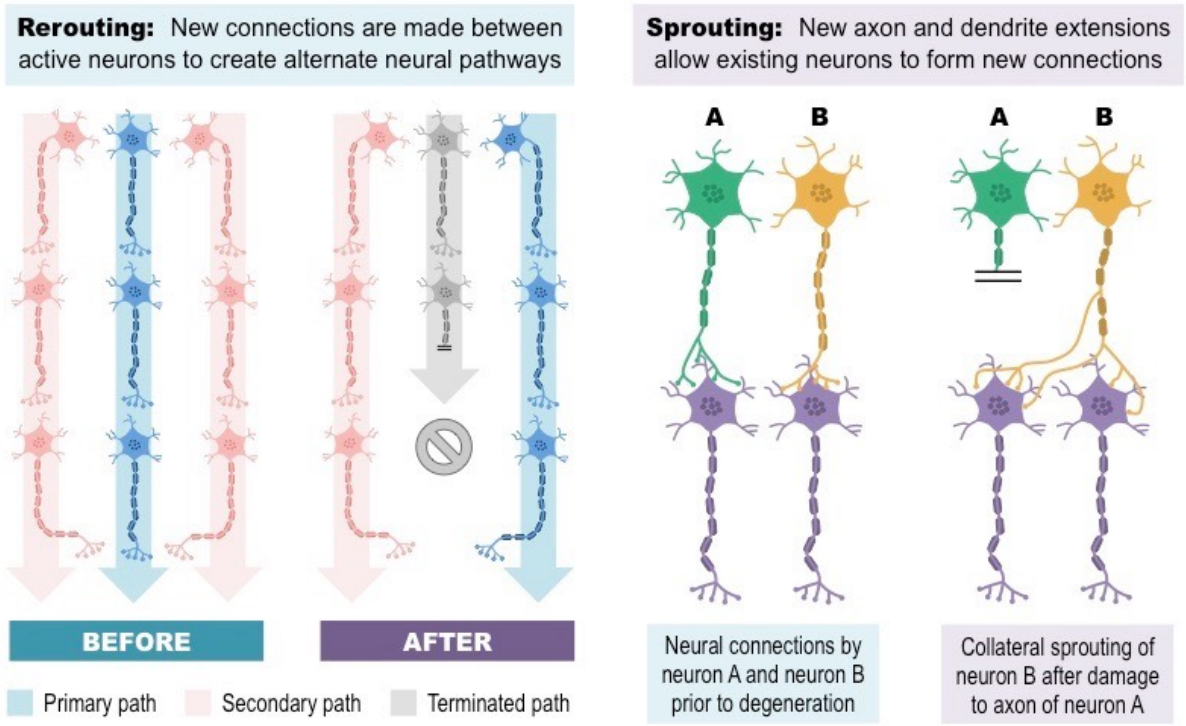


Figure 2: Rerouting and Sprouting

In order to understand neuroplasticity, a closer look at the synapse formation and synaptic pruning will be helpful. An infant brain contains about 15,000 synapses (connection between a neuron and another cell near that neuron) per neuron. It contains billions of neurons. So, the size and complexity of network in an infant brain is immense. Number of the neurons don't change significantly in the adult brain, but number of synapses have to be reduced. Babies learn literally everything from a fresh start, so they need to have the infrastructure in their brain that can support the massive input of new sensory data and consolidate innumerable memories. Adults, on the other hand, will not be learning that many things every day, they need circuits that will allow them to access useful information for their daily lives. This is made possible

by enhancing the synaptic connections for that frequently used information. That information will be different for every individual. A professional pianist and a heart surgeon will have different pathways in their brains as a result of enhancing different synapses. Therefore, infant brain will start to reduce the synaptic connections after the age of two, this is called synapse pruning.

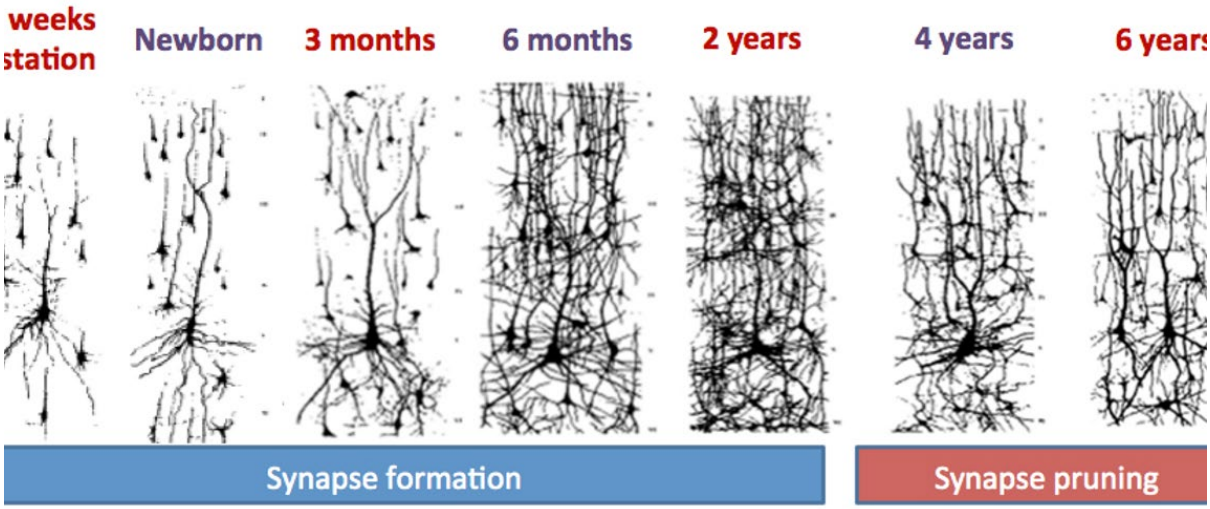


Figure 3: Periods of Synapse Formation and Synapse Pruning

One of the reasons why scientists used to think that the brain was not plastic was that they believed neurogenesis couldn't occur in the adult brain. Without neurogenesis, formation of new neurons, brain couldn't be altered. Fred Gage proved neurogenesis in the human brain, and with this new information it became more accepted that the brain could actually change its structure. Neurogenesis can be even improved with the implantation of pluripotent[1] stem cells in the hippocampus.

Marian Diamond determined five key components for increased positive plasticity gain in the brain: newness, challenge, diet, exercise, love. Newness and challenge are essential for enhanced cognitive function. Enjoyment of the task and undivided focus increases the efficacy of the challenge on the brain plasticity gain. "New and enriching experiences resulted in decreased age dependent degeneration as shown by less accumulation of lipofuscin in the dentate gyrus." (Shaffer). The risk of developing

[1] Stem cells that are capable of indefinite differentiation, they can divide and differentiate to form any kind of human tissue.

mild cognitive (MCI) impairment at an old age depends on the newness and challenge presented to the brain at early ages. Learning foreign languages and musical instruments in adolescence significantly decrease the risk developing (MCI) after 70 years of age. Music is a really important enrichment for positive plasticity gain: "individuals with an average age of 26.45 found that the anterior prefrontal cortex played a central role and that the neuroplastic response was greater in musicians with long term training than was noted in those with short term training" (Paraskevopoulos et al.). Exercise is also found to increase motor neuron responses and neurogenesis in the brain. Calorie restriction and intermittent diet show increased cognitive functioning and more resistant neurons to injury. Adequate and quality sleep is essential for cognitive functioning: "Chronic insomnia in humans was associated with hippocampal atrophy that suggests decreased neurogenesis." (Joo et al.) Accumulated sleep deprivation may lead to irreversible reduction in neurogenesis and in white matter integrity in the brain.

Plasticity doesn't always have positive effects on the brain. Drug and alcohol abuse, sleep deprivation is it was briefly discussed earlier, and stress can negatively change the structure of the brain. Hippocampal synaptic plasticity, modelled by long-term potentiation[2] (LTP), is a key contributor to memory formation. Chronic or severe stress impairs LTP and thus, hypothalamus-dependent memory. Stress also has negative impacts on the prefrontal cortex, it causes the regression of apical dendrites of pyramidal cells. Stress-induced reduction of glia (a type of brain cell) affects neuroplasticity. Effects of stress on amygdala are distinguished from the effects on prefrontal cortex and hypothalamus. Amygdala's size and activity increases with stress especially in major depression cases. Amygdala-dependent learning is enhanced with stress, this is why stressful and frightening memories are usually stronger. Therefore, neuroplasticity is advanced in the amygdala in response to stress.

[2] Long term potentiation is the biological process by which certain types of synaptic stimulation – such as prolonged high frequency input- result in a long-lasting increase in the strength of synaptic transmission. (Nature research, Long-term potentiation)

Chemicals that promote and inhibit neuroplasticity in the brain include inhibitory activity of GABAergic parvalbumin positive (PV+) cells, perineuronal nets, and myelin associated proteins[3]. As it can be interpreted from the previously discussed findings, working mechanisms of such chemicals are complex and inclined to depend on where they act on in the brain.

Neuroplasticity of the brain allows us to learn, remember, and change as a person. Environmental factors are of prime importance in determining the particular effect on neuroplasticity. It can be harmful, or very enriching for us. We are lucky that our brains have this remarkable ability that makes the life ahead of us full of new experiences.

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[3] GABA is an inhibitory neurotransmitter that decreases the probability of initiating an action potential. Parvalbumin is a kind of protein that is largely found in the brain and muscle cells. Perineuronal nets are extracellular matrix structures that enable synaptic stabilization in the adult brain. Myelin is a fatty substance located on the axon and facilitates electrical signal transmission from the soma to the axon terminal.

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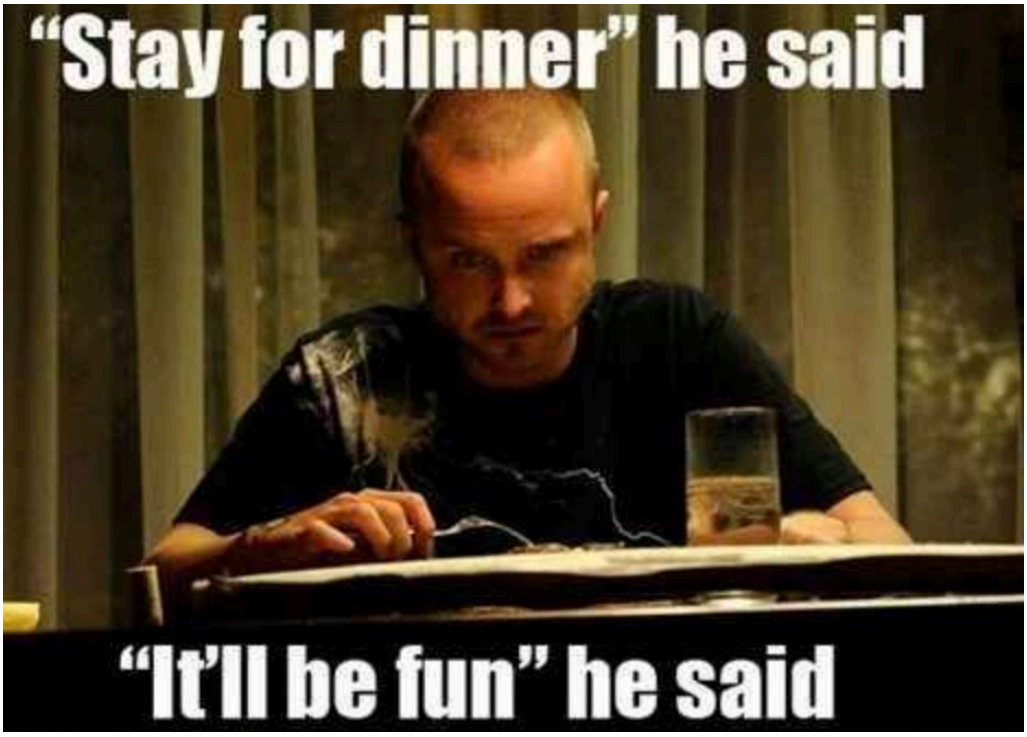
Maybe She's Born with It,



Maybe It's Methamphetamine?

Eylül Ustaoğlu

Disclaimer! Methamphetamine is one of the drugs everybody knows is highly dangerous, but how much do we know about it? Writing this article, I intended to explain the chemical structure and the science that goes behind this substance. The article also aims to acknowledge the deadly effects of meth. The article is only for educational purposes. According to World Health Organization (WHO), **around half a million people die** because of drug abuse every year. Don't do drugs kids! With that being said, we shall proceed.

First things first, what is Methamphetamine? Methamphetamine is a potent stimulant of the amphetamine chemical class that is highly addictive and affects the central nervous system. Also known, among many other words, as meth, blue, ice, and crystal, it takes the form of a white, odorless, bitter-tasting crystalline powder that dissolves easily in water or alcohol. Just like many synthetic stimulants, meth has the power to create addiction in the consumer in a very short time due to its rapid effect and long-lasting euphoria.

The history of Methamphetamine goes back to late 19th century. After Nagai Nagayoshi synthesized the first Ephedrine in 1893, the first crystalized meth was manufactured by reduction method (also known as Nagai Method). Even though there are many synthetic routes to manufacture meth, the most used way in illicit trafficking is still this method. The reduction of ephedrine or pseudoephedrine with hydriodic acid and red phosphorus is commonly known as "HI/Red P", and it is a relatively simple method.

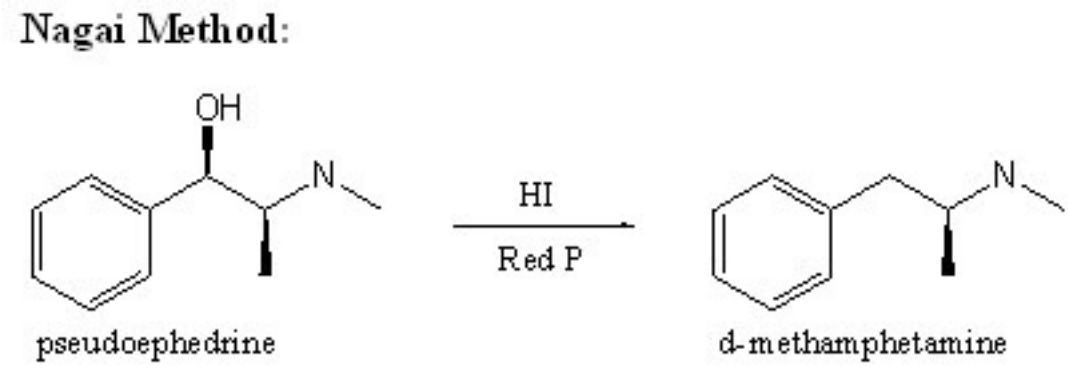


Figure 1: The Visual Representation of the "HI/Red P" Reduction and the Chemical Structure of Methamphetamine

Pseudoephedrine is a widely used chemical in pharmacology, and it almost has the same structure with methamphetamine besides the hydroxyl group. Only reducing the hydroxyl group with a simple reaction turns an everyday medicine to a highly addictive psychoactive fatal drug.

Another commonly used method in the manufacture of this substance is called the "2P2 Method". Reductive amination is a form of amination that involves the conversion of a carbonyl group to an amine via an intermediate imine. First, Phenylacetone (2P2) is generated via dehydrocarboxylation using phenylacetic acid and acetic acid.

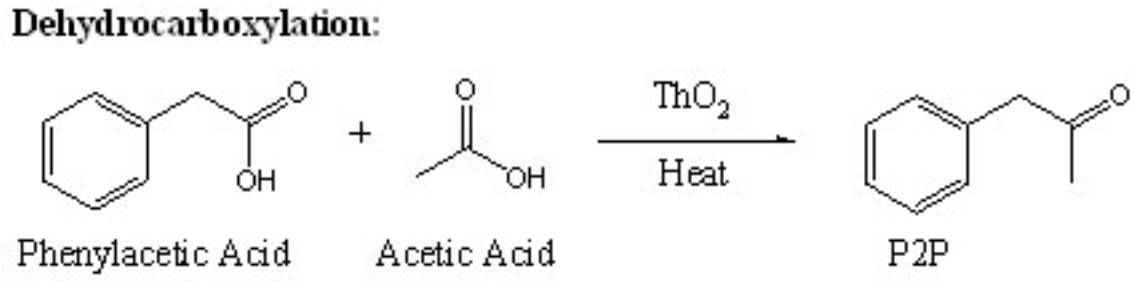


Figure 2: Synthesis of 2P2 via Dehydrocarboxylation Reaction

After this step, a reaction between phenylacetone and methylamine occurs and generates imine. Then, as stated before, reductive amination method takes place and imine is reduced.

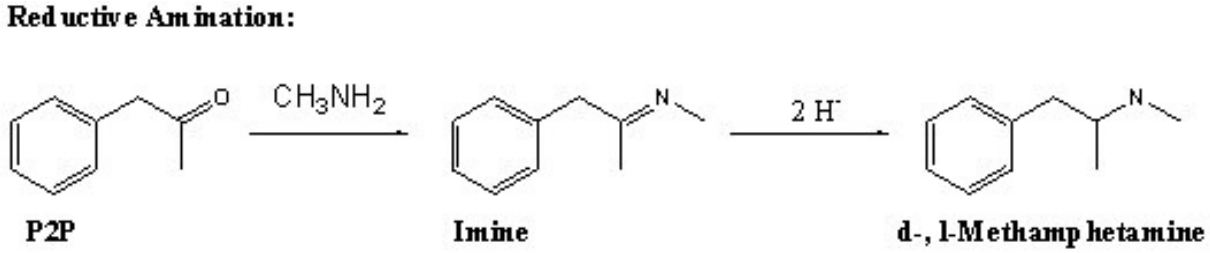


Figure 3: Synthesis of d-methamphetamine, Meth, via Reductive Amination

Last but not least, another commonly used method to manufacture meth is "Birch Reduction" method. During WWII, methamphetamine was used in the armed forces because of its wakefulness effect. Because of this reason, the Birch reduction method is also known as the "Nazi Method". Without further ado, let's see how this method works.

The Birch reduction is an organic reaction that is used to convert arenes to cyclohexadienes, and in this case, it consists of ephedrine or pseudoephedrine reaction

with anhydrous ammonia and alkali metals. This method is relatively more complex giving the reactivity of ammonia and alkali metals.

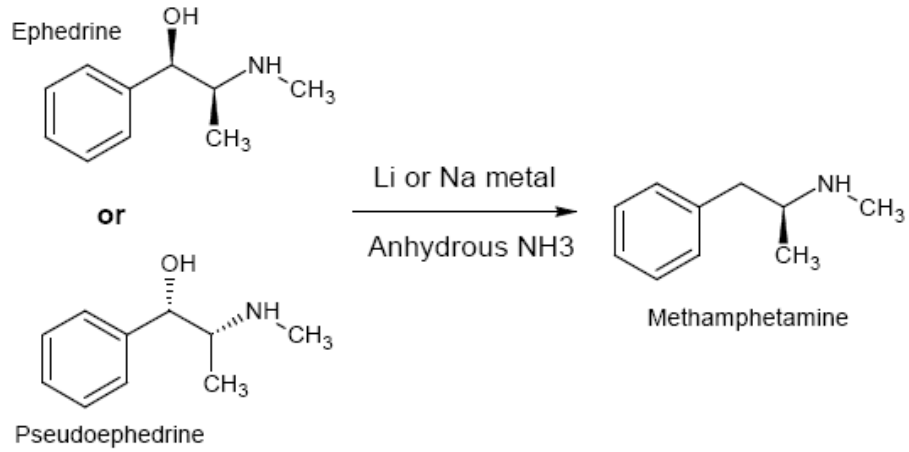


Figure 4: d-Methamphetamine Synthesis via Birch Reduction

As stated before, pseudoephedrine and ephedrine are commonly used to manufacture methamphetamine and it is very interesting how an everyday drug turns into one of the most dangerous street drugs just with the reduction of hydroxyl group. But what is more interesting is that the enantiomer of methamphetamine, L-methamphetamine, is also used in everyday medicine, mostly in nasal decongestants. Although they have the same boiling point, the same molecular mass and the same chemical formula, they have quite different 3-dimensional structures.

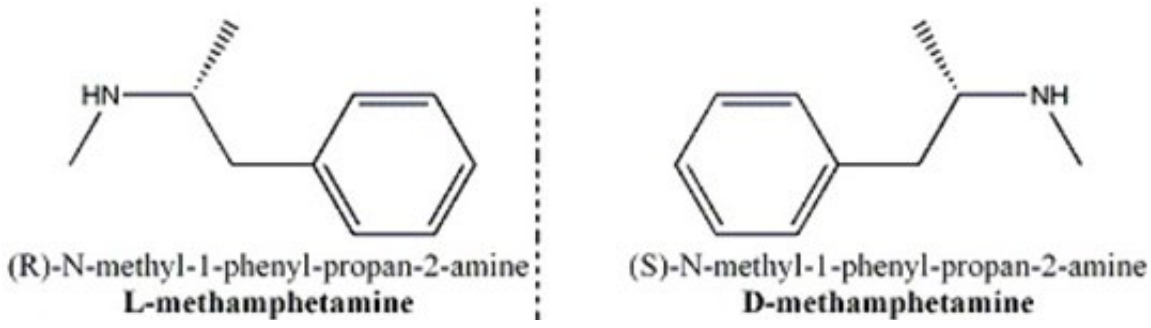


Figure 5: The Chemical Structure of "Meth" and Its Stereoisomer.

Although they seem quite the same, converting one to another is highly dangerous and requires advanced lab equipment. After decades of people trying to convert l-

methamphetamine, nasal decongestant, into d-methamphetamine, meth, the name of the substance was changed into Levomethamphetamine by the manufacturers to minimize the illicit trafficking.

When we stated that the effects of methamphetamine are very deadly, what did we really mean? Because it is a powerful stimulant, even in very small doses, meth can increase your wakefulness and cause you hyperactivity, it also has effects of euphoria, alertness, concentration and apprehension, and self-confidence. These are the reasons why people consume meth. But what are the deadly effects? Meth causes a loss of appetite, dilated pupils, flushed skin, excessive sweating, dry mouth and teeth grinding (later on turns into the syndrome called "meth mouth"), dry skin, acne and many more. Also, any consumption more than 200 mg is considered fatal.

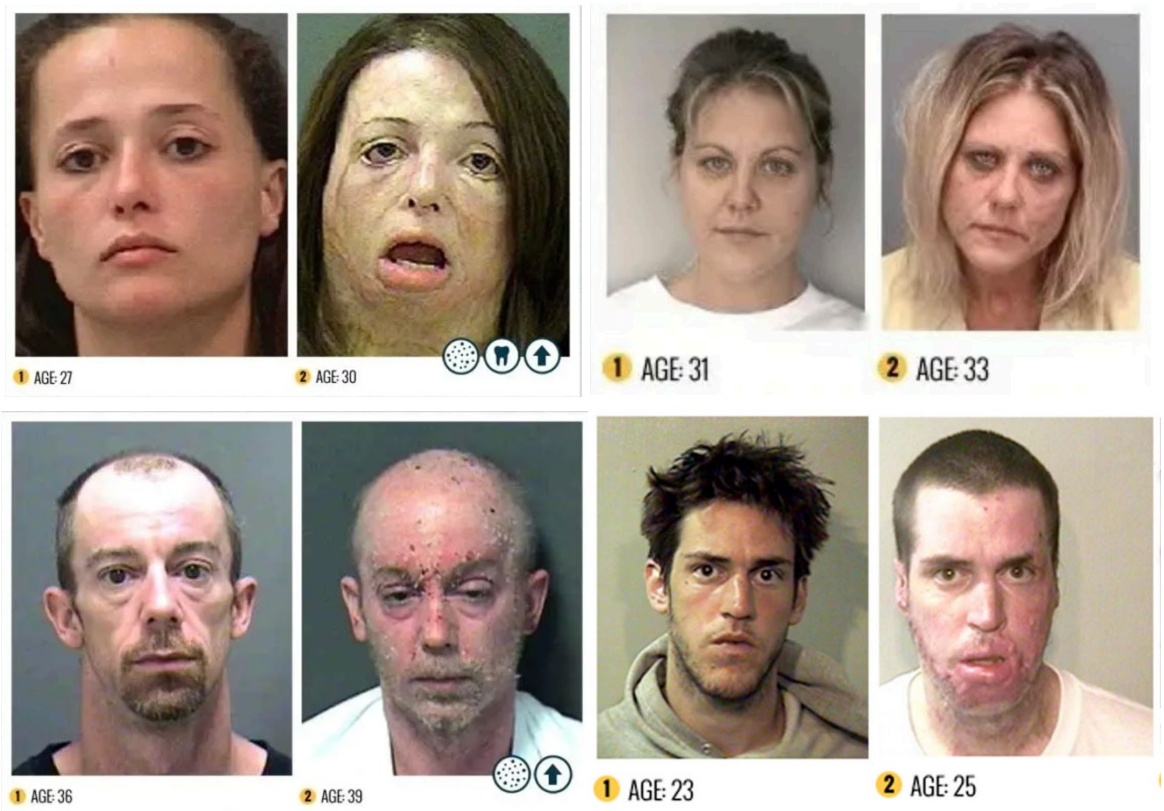


Figure 6: Before-after Mugshots of the People Who Use Methamphetamine

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Quantum Gravity

$$\mathcal{L}_{SM} = -\frac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \frac{1}{4}g^2_s f^{abc} f^{ade} g^b_\mu g^c_\nu g^d_\mu g^e_\nu - \partial_\nu W^+_\mu \partial_\nu W^-_\mu - M^2 W^+_\mu W^-_\mu - \frac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \frac{1}{2c^2_w} M^2 Z^0_\mu Z^0_\mu - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - igc_w(\partial_\nu Z^0_\mu (W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - Z^0_\nu (W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + Z^0_\mu (W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)) - igs_w(\partial_\nu A_\mu (W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - A_\nu (W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + A_\mu (W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)) - \frac{1}{2}g^2 W^+_\mu W^-_\mu W^+_\mu W^-_\nu + \frac{1}{2}g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2 c^2_w (Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) + g^2 s^2_w (A_\mu W^+_\mu A_\nu W^-_\nu - A_\mu A_\mu W^+_\nu W^-_\nu) + g^2 s_w c_w (A_\mu Z^0_\mu (W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - 2A_\mu Z^0_\mu W^+_\nu W^-_\nu) - \frac{1}{2}\partial_\mu H \partial_\mu H - 2M^2 \alpha_h H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - \frac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \beta_h \left(\frac{2M^2}{g^2} + \frac{2M}{g} H + \frac{1}{2}(H^2 + \phi^0\phi^0 + 2\phi^+\phi^-) \right) + \frac{2M^4}{g^2}\alpha_h - g\alpha_h M (H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-) - \frac{1}{8}g^2 \alpha_h (H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- + 2(\phi^0)^2 H^2) - gMW^+_\mu W^-_\mu H - \frac{1}{2}g\frac{M}{c^2_w} Z^0_\mu Z^0_\mu H - \frac{1}{2}ig\left(W^+_\mu(\phi^0\partial_\mu\phi^- - \phi^-\partial_\mu\phi^0) - W^-_\mu(\phi^0\partial_\mu\phi^+ - \phi^+\partial_\mu\phi^0)\right) + \frac{1}{2}g\left(W^+_\mu(H\partial_\mu\phi^- - \phi^-\partial_\mu H) + W^-_\mu(H\partial_\mu\phi^+ - \phi^+\partial_\mu H)\right) + \frac{1}{2}g\frac{1}{c_w}(Z^0_\mu(H\partial_\mu\phi^0 - \phi^0\partial_\mu H) + M\left(\frac{1}{c_w}Z^0_\mu\partial_\mu\phi^0 + W^+_\mu\partial_\mu\phi^- + W^-_\mu\partial_\mu\phi^+\right) - ig\frac{s^2_w}{c_w}MZ^0_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) + igs_wMA_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) - ig\frac{1-2c^2_w}{2c_w}Z^0_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) + igs_wA_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - \frac{1}{4}g^2W^+_\mu W^-_\mu (H^2 + (\phi^0)^2 + 2\phi^+\phi^-) - \frac{1}{8}g^2\frac{1}{c^2_w}Z^0_\mu Z^0_\mu (H^2 + (\phi^0)^2 + 2(2s^2_w - 1)^2\phi^+\phi^-) - \frac{1}{2}g^2\frac{s^2_w}{c_w}Z^0_\mu\phi^0(W^+_\mu\phi^- + W^-_\mu\phi^+) - \frac{1}{2}ig^2\frac{s^2_w}{c_w}Z^0_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) + \frac{1}{2}g^2 s_w A_\mu\phi^0(W^+_\mu\phi^- + W^-_\mu\phi^+) + \frac{1}{2}ig^2 s_w A_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) - g^2\frac{s_w}{c_w}(2c^2_w - 1)Z^0_\mu A_\mu\phi^+\phi^- - g^2 s^2_w A_\mu A_\mu\phi^+\phi^- + \frac{1}{2}ig_s\lambda^a_{ij}(\bar{q}^i_\sigma\gamma^\mu q^j_\sigma)g^a_\mu - \bar{e}^\lambda(\gamma\partial + m^\lambda_e)e^\lambda - \bar{\nu}^\lambda(\gamma\partial + m^\lambda_\nu)\nu^\lambda - \bar{u}^\lambda_j(\gamma\partial + m^\lambda_u)u^\lambda_j - \bar{d}^\lambda_j(\gamma\partial + m^\lambda_d)d^\lambda_j + igs_wA_\mu\left(-(\bar{e}^\lambda\gamma^\mu e^\lambda) + \frac{2}{3}(\bar{u}^\lambda_j\gamma^\mu u^\lambda_j) - \frac{1}{3}(\bar{d}^\lambda_j\gamma^\mu d^\lambda_j)\right) + \frac{ig}{4c_w}Z^0_\mu\{(\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{e}^\lambda\gamma^\mu(4s^2_w - 1 - \gamma^5)e^\lambda) + (\bar{d}^\lambda_j\gamma^\mu(\frac{4}{3}s^2_w - 1 - \gamma^5)d^\lambda_j) + (\bar{u}^\lambda_j\gamma^\mu(1 - \frac{8}{3}s^2_w + \gamma^5)u^\lambda_j)\} + \frac{ig}{2\sqrt{2}}W^+_\mu\left((\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)U^{lep}_{\lambda\kappa}e^\kappa) + (\bar{u}^\lambda_j\gamma^\mu(1+\gamma^5)C_{\lambda\kappa}d^\kappa_j)\right) + \frac{ig}{2\sqrt{2}}W^-_\mu\left((\bar{e}^\kappa U^{lep\dagger}_{\kappa\lambda}\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{d}^\kappa_j C^\dagger_{\kappa\lambda}\gamma^\mu(1+\gamma^5)u^\lambda_j)\right) + \frac{ig}{2M\sqrt{2}}\phi^+\left(-m^\kappa_e(\bar{\nu}^\lambda U^{lep}_{\lambda\kappa}(1-\gamma^5)e^\kappa) + m^\lambda_\nu(\bar{\nu}^\lambda U^{lep}_{\lambda\kappa}(1+\gamma^5)e^\kappa) + \frac{ig}{2M\sqrt{2}}\phi^-\left(m^\lambda_e(\bar{e}^\lambda U^{lep\dagger}_{\lambda\kappa}(1+\gamma^5)\nu^\kappa) - m^\kappa_\nu(\bar{e}^\lambda U^{lep\dagger}_{\lambda\kappa}(1-\gamma^5)\nu^\kappa)\right) - \frac{g}{2}\frac{m^\lambda_e}{M}H(\bar{\nu}^\lambda\nu^\lambda) - \frac{g}{2}\frac{m^\lambda_e}{M}H(\bar{e}^\lambda e^\lambda) + \frac{ig}{2}\frac{m^\lambda_\nu}{M}\phi^0(\bar{\nu}^\lambda\gamma^5\nu^\lambda) - \frac{ig}{2}\frac{m^\lambda_e}{M}\phi^0(\bar{e}^\lambda\gamma^5 e^\lambda) - \frac{1}{4}\bar{\nu}_\lambda M^R_{\lambda\kappa}(1-\gamma_5)\bar{\nu}_\kappa - \frac{1}{4}\bar{\nu}_\lambda M^R_{\lambda\kappa}(1-\gamma_5)\bar{\nu}_\kappa + \frac{ig}{2M\sqrt{2}}\phi^+\left(-m^\kappa_d(\bar{u}^\lambda_j C_{\lambda\kappa}(1-\gamma^5)d^\kappa_j) + m^\lambda_u(\bar{u}^\lambda_j C_{\lambda\kappa}(1+\gamma^5)d^\kappa_j)\right) + \frac{ig}{2M\sqrt{2}}\phi^-\left(m^\lambda_d(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1+\gamma^5)u^\kappa_j) - m^\kappa_u(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1-\gamma^5)u^\kappa_j)\right) - \frac{g}{2}\frac{m^\lambda_u}{M}H(\bar{u}^\lambda_j u^\lambda_j) - \frac{g}{2}\frac{m^\lambda_d}{M}H(\bar{d}^\lambda_j d^\lambda_j) + \frac{ig}{2}\frac{m^\lambda_u}{M}\phi^0(\bar{u}^\lambda_j\gamma^5 u^\lambda_j) - \frac{ig}{2}\frac{m^\lambda_d}{M}\phi^0(\bar{d}^\lambda_j\gamma^5 d^\lambda_j) + \bar{G}^a\partial^2 G^a + g_s f^{abc}\partial_\mu\bar{G}^a G^b g^c_\mu + \bar{X}^+(\partial^2 - M^2)X^+ + \bar{X}^-(\partial^2 - M^2)X^- + \bar{X}^0(\partial^2 - \frac{M^2}{c^2_w})X^0 + \bar{Y}\partial^2 Y + igc_w W^+_\mu(\partial_\mu\bar{X}^0X^- - \partial_\mu\bar{X}^+X^0) + igs_w W^+_\mu(\partial_\mu\bar{Y}X^- - \partial_\mu\bar{X}^+Y) + igc_w W^-_\mu(\partial_\mu\bar{X}^-X^0 - \partial_\mu\bar{X}^0X^+) + igs_w W^-_\mu(\partial_\mu\bar{X}^-Y - \partial_\mu\bar{Y}X^+) + igc_w Z^0_\mu(\partial_\mu\bar{X}^+X^+ - \partial_\mu\bar{X}^-X^-) + igs_w A_\mu(\partial_\mu\bar{X}^+X^+ - \partial_\mu\bar{X}^-X^-) - \frac{1}{2}gM\left(\bar{X}^+X^+H + \bar{X}^-X^-H + \frac{1}{c^2_w}\bar{X}^0X^0H\right) + \frac{1-2c^2_w}{2c_w}igM\left(\bar{X}^+X^0\phi^+ - \bar{X}^-X^0\phi^-\right) + \frac{1}{2c_w}igM\left(\bar{X}^0X^-\phi^+ - \bar{X}^0X^+\phi^-\right) + igMs_w\left(\bar{X}^0X^-\phi^+ - \bar{X}^0X^+\phi^-\right) + \frac{1}{2}igM\left(\bar{X}^+X^+\phi^0 - \bar{X}^-X^-\phi^0\right).$$

Elif Ilgın Özdemir, Hüseyin Yağız Devre

20th century was the beginning of the paradigm-shifting discoveries upon quantum physics. Scientists came much closer to a theory of everything than before, yet still could not integrate all theories into a single unified theory. Quantum mechanics and the general theory of relativity were the two theories which if combined would yield the wanted result. However, both were contradictory to one another, thereby preventing a final result. Quantum Gravity still remains one of the unexplained concepts to this day.

Background of Quantum Gravity:

Quantum Mechanics

Quantum Mechanics is the foundation of all quantum branches out there, it investigates the characteristics of subatomic particles and how they are and how they interact. The mathematical approach of Quantum Mechanics started with Schrödinger's equation:

$$i\hbar\frac{\partial}{\partial t}\psi(r,t) = -\frac{\hbar^2}{2m}\nabla^2\psi(r,t) + V(r,t)\psi(r,t)$$

This equation essentially tracks the possibility of the wavelike treated particles in the spacetime. However, it uses a Newtonian approach, meaning that it treats space and time as separate concepts. This issue was then tried to be solved by Paul Dirac, by adding a relativistic wave equation for the electron. Tying the cornerstones of quantum theory and the general relativity.

$$\left(\mathbf{i}\hbar\boldsymbol{\gamma}^{\boldsymbol{\mu}}\boldsymbol{\nabla}_{\boldsymbol{\mu}} - \mathbf{mc}\right)\boldsymbol{\psi} = \mathbf{0}$$

Figure 1: Dirac Equation

Two of the fundamental ideas in Quantum Mechanics are Superposition and Quantum Entanglement respectively.

Superposition:

Superposition, as the naming suggests, is essentially the idea of being in 2 different states at the same time. In Quantum Mechanics, the idea is the same, but on a smaller scale. Particles, for instance electrons, exhibit some features such as spin, charge and mass. As the standard model, see Figure 4, suggests an electron has a charge of -1 and a spin of ½. The term "Spin" is essentially the intrinsic angular momentum of the particle, if we are talking about point particles. In Quantum Mechanics, as the Stern-Gerlach experiment shown in the Figure 2 demonstrated, silver atoms travelling through a magnetic field have both spins at the same time, commonly referred to as spin-up and spin-down. In this case, a silver atom or an electron has the final chance of being spin-up and spin-down until we measure it. It is the

same idea of a coin that landed on both heads and tails at the same time. And this idea was the basis of the famous thought experiment called Schrödinger's Cat. Erwin Schrödinger questioned whether an animal's life could be in a superposition too when it is connected to the state of a particle.

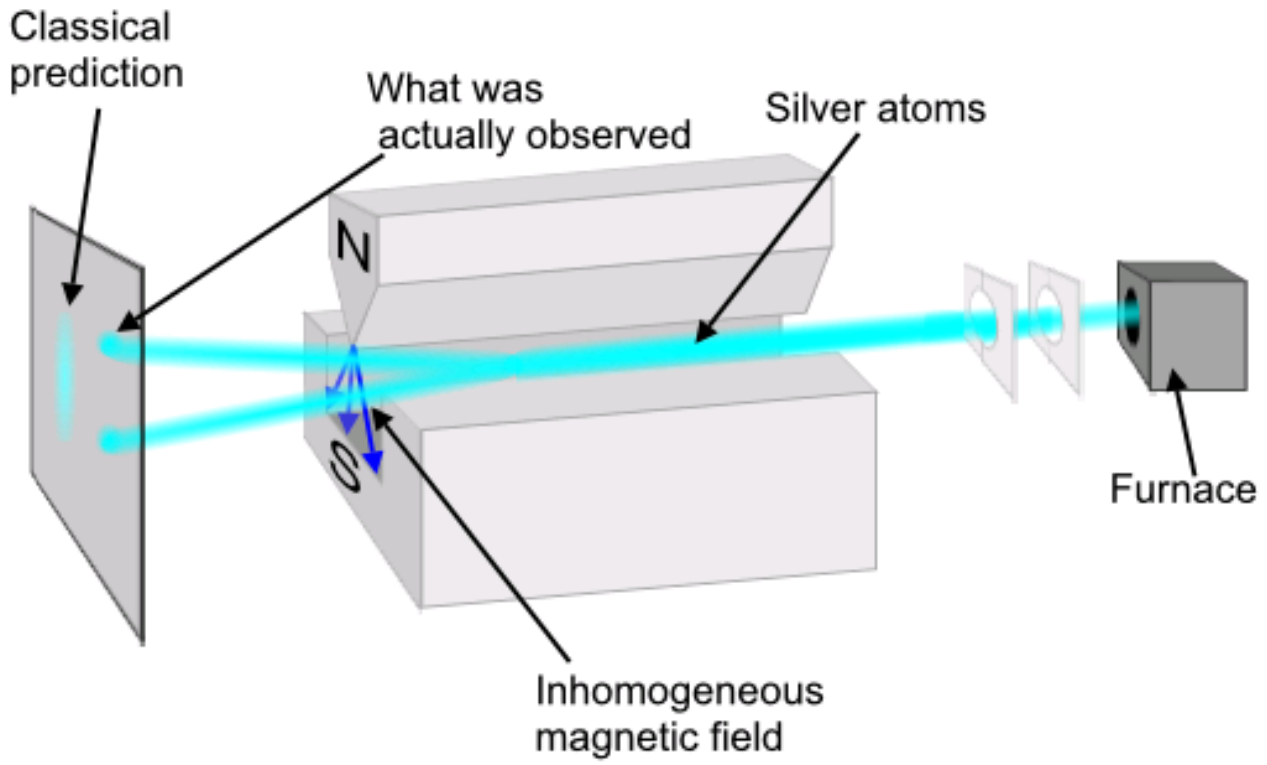

Figure 2: Experimental Setup of Stern-Gerlach

Quantum Entanglement:

Quantum Entanglement is in fact a bizarre concept to understand. Imagine that you had a pair of shoes. And let's say that one of the shoes has a black spot on it. If you put these shoes in separate boxes and open one of them at random, you would immediately understand which shoe is in which box and which shoe has the spot on it. In this case, knowing the state/information about one of the shoes immediately provides significant information about the other one. In such a case it could be stated that these pairs of shoes are entangled.

In the scale of a particle, the process is roughly the same, if the state of an electron is known by measuring it, then its entangled partner's state could be known without measuring. Einstein found this phenomenon "spooky" and called it "Spooky action at a distance".

According to Niels Bohr, both of the entangled partners' states became real and definite at the same time.

General Relativity

General Relativity is Einstein's famous theory of relativity. Simply stated, the existence of mass and energy create curvatures in spacetime, which then we refer to as gravity. It also is connected to the previous special theory of relativity which claims that our perceptions of the spacetime are dependent on the motion. The most common knowledge of gravity, Newtonian gravity, unlike general and special relativity, treats both space and time as separate and absolute concepts, however Einstein's relativity theories unify the concepts.

$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} + \Lambda\, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Figure 3: General Relativity Equation

There are around 10 equations of the General Relativity but this encapsulates all of them. It basically summarizes how stress-energy-momentum tensor affects the curvature of spacetime.

However, the aforementioned General Relativity contradicts with the quantum theory. Both are proven yet, not in line with one another. As mentioned before quantum theory suggests superposition which means a particle can exist in multiple locations at the same time, but then where will the spacetime curvatures will occur? General Relativity does not take superposition into account.

Another issue is with black holes, where the General Relativity math doesn't add up. The reason is, General Relativity treats spacetime as mathematically flat at infinitesimally small distances. However, a blackhole will create an infinite curvature at an infinitely small point, causing a singularity. Singularities also don't work with General Relativity equations. The main question upon quantum gravity is whether or not the two aforementioned concepts can be integrated or not. There are many theories put forth to tackle this problem, yet the

most famous ones are the ones discussed below. The next section will be handling all in a detailed perspective.

Theories to Unify Quantum Gravity:

The most reliable theory for the fundamental building blocks of the nature is the standard model. It has fermions from which the matter is composed of and bosons from which the forces are made up of.

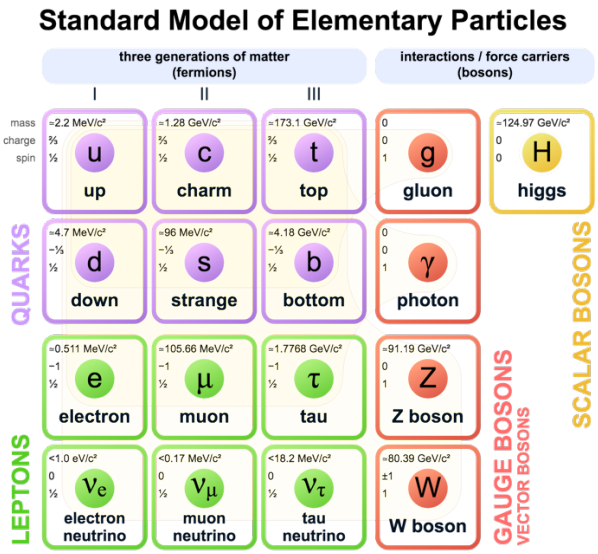

Figure 4: The Standard Model of Particles

They may look as simple as the table shows but there are numerous equations behind them which construct their existence

$$
\begin{aligned}
\mathcal{L} = & -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{8}tr(\mathbf{W}_{\mu\nu}\mathbf{W}^{\mu\nu}) - \frac{1}{2}tr(\mathbf{G}_{\mu\nu}\mathbf{G}^{\mu\nu}) && \text{(U(1), SU(2) and SU(3) gauge terms)} \\
& + (\bar{\nu}_L, \bar{e}_L)\bar{\sigma}^\mu i D_\mu \begin{pmatrix} \nu_L \\ e_L \end{pmatrix} + \bar{e}_R \sigma^\mu i D_\mu e_R + \bar{\nu}_R \sigma^\mu i D_\mu \nu_R + (\text{h.c.}) && \text{(lepton dynamical term)} \\
& - \frac{\sqrt{2}}{v}\left[(\bar{\nu}_L, \bar{e}_L)\phi M^e e_R + \bar{e}_R \bar{M}^e \bar{\phi} \begin{pmatrix} \nu_L \\ e_L \end{pmatrix} \right] && \text{(electron, muon, tauon mass term)} \\
& - \frac{\sqrt{2}}{v}\left[(-\bar{e}_L, \bar{\nu}_L)\phi^* M^\nu \nu_R + \bar{\nu}_R \bar{M}^\nu \phi^T \begin{pmatrix} -e_L \\ \nu_L \end{pmatrix} \right] && \text{(neutrino mass term)} \\
& + (\bar{u}_L, \bar{d}_L)\bar{\sigma}^\mu i D_\mu \begin{pmatrix} u_L \\ d_L \end{pmatrix} + \bar{u}_R \sigma^\mu i D_\mu u_R + \bar{d}_R \sigma^\mu i D_\mu d_R + (\text{h.c.}) && \text{(quark dynamical term)} \\
& - \frac{\sqrt{2}}{v}\left[(\bar{u}_L, \bar{d}_L)\phi M^d d_R + \bar{d}_R \bar{M}^d \bar{\phi} \begin{pmatrix} u_L \\ d_L \end{pmatrix} \right] && \text{(down, strange, bottom mass term)} \\
& - \frac{\sqrt{2}}{v}\left[(-\bar{d}_L, \bar{u}_L)\phi^* M^u u_R + \bar{u}_R \bar{M}^u \phi^T \begin{pmatrix} -d_L \\ u_L \end{pmatrix} \right] && \text{(up, charmed, top mass term)} \\
& + \overline{(D_\mu \phi)} D^\mu \phi - m_h^2[\bar{\phi}\phi - v^2/2]^2/2v^2. && \text{(Higgs dynamical and mass term)} \quad (1)
\end{aligned}
$$

Figure 5: The Lagrangian of the Standard Model

Now looking at these bosons, (electromagnetism, strong force, and weak forces) it can be noticed that there is no correspondent for gravity. This is because the general relativity dictates that the gravity is not conferring a force but it is the warping of the background of spacetime itself.

1. String Theory

String Theory solves this inconvenience between Quantum Mechanics and General Relativity by changing our perception upon understanding the universe. Compared to our modern understanding of our universe, which depends on the intuition that the elementary subatomic particles such as electrons, neutrinos and quarks are actually point particles, String Theory suggests that all the electrons, neutrinos, muons etc. are the result of vibration on a string.

To make it simpler, imagine a violin. In a certain frequency and amplitude, the string produces what we observe as note "D"; in another frequency and amplitude, the string produces what we observe as note "G". Similar to a violin string, one dimensional filaments called strings vibrate in a unique way to produce a gluon, they vibrate in another way and they produce an electron.

From the perspective of mathematics, String Theory actually works. Its mathematics actually combines and unifies both theories in physics, Quantum Mechanics and General Relativity respectively. On the contrary, String Theory comes with a drawback called Higher Dimensions. String Theory requires 6 additional dimensions on top of the 4 dimensions that we know. So, in this case, String Theory works in a 10-dimensional universe compared to our 4D universe that we know.

On the other hand, there is a solution to this problem by using intuition. Imagine observing a planet from far away. That planet would look like a point. If you sent a satellite, you would observe its dimensions such as height and width. After that, you would observe its area which is 2D. When the satellite comes close enough, you would observe its depth as well. Intuitively, if we come closer to an object, we would observe more dimensions.

Furthermore, physicists think that there could be a geometric shape called "Calabi Yau Manifold", as shown in Figure 6, which allows the strings to vibrate. Interestingly, the Calabi Yau Manifold has different forms and versions which hints that each different version could cause a parallel universe.

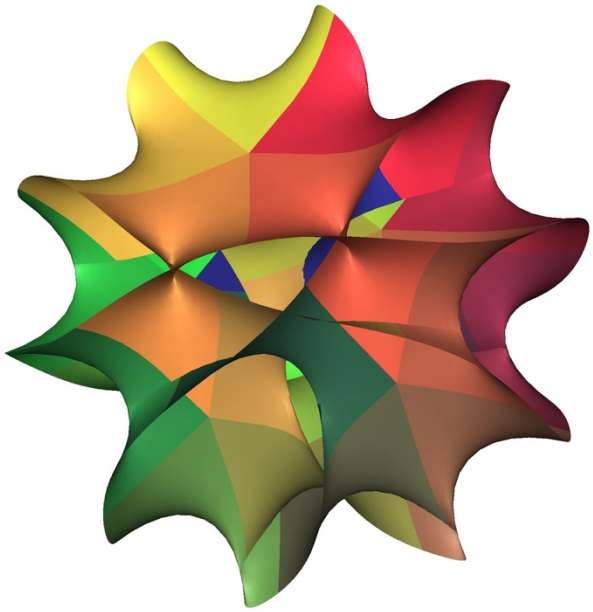

Figure 6: Calabi-Yau Manifold

2. Loop Quantum Gravity

Briefly, LQG claims that the background spacetime itself is maybe quantized, unlike Einstein's claim of continuous spacetime, but made up of discrete quanta. This assumption is different in every other quantum gravity theory than LQG. Even the string theory itself admits the spacetime is a background on which the strings vibrate. However, LQG takes the background quantized and background distance has a minimum value of a Planck length.

The spacetime is made up of infinite loops with little nodes connecting them to one another. The intersection points of these nodes reflect where the quanta volume of the space reside.

The loops between each node represent 2D areas. This whole node loop structure is then called a spin network as their characteristics are related to a property referred to as spin.

Theory is that space is the geometry of the network itself and the time is the movement of this network. These two properties combined produces a spin foam. In a spin foam, time ticks with quantum ticks. It is not like a continuous flow. When mass and energy is added to this spin network, a spacetime distortion occurs. Time in this case is the movement of this volume quanta.

Interesting thing about LQG is that it puts forth some testable predictions which makes it compelling to the eye.

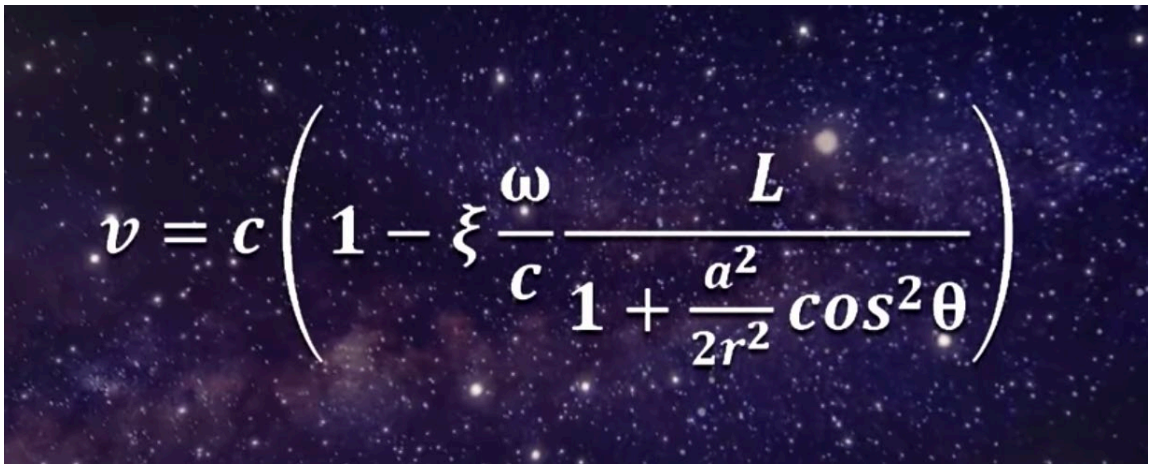

Figure 7: Math of Loop Quantum Gravity

As also shown in the equation above, one of these is that the speed of light is dependent on the energy (frequency of light). Photons with higher energy travel slower compared to low energy ones. This puts forth an LQG prediction which claims that two photons that have different frequencies which are emitted from a gamma ray burst from far away should reach the Earth in different amount of time. However, this is not yet recorded by an observation device, and therefore, not definitively proven.

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