Siemens Competition
Math : Science : Technology
Regional Finalist

Names: Kenneth Jiao
High School: Indian Springs School
Mentor: Dr. Lizhong Wang
Project Title: Retain CHD7, an Epigenetic Regulator, in the Nucleus to Combat Breast Cancer Metastasis

Metastasis accounts for ~90% of breast cancer (BC) deaths. My study aims to address the fundamental question of how BC cells in the primary tumor become metastatic. CHD7 is an ATP dependent nucleosome remodeling factor that acts in the nucleus to epigenetically regulate gene expression. I found that CHD7 is localized in the nucleus in a low metastatic BC cell line. However, in highly metastatic BC cell lines, CHD7 is primarily localized in the cytoplasm, where it is unable to function. This result was further confirmed using invasive human BC samples. Therefore, I hypothesized that exporting CHD7 into the cytoplasm plays a critical role in the metastasis of BC cells. Through reporter analyses, I identified a nuclear export signal (NES) sequence of CHD7 in metastatic MDA-MB-231 cells. Mutating the NES sequence through CRISPR/Cas9 caused an accumulation of CHD7 in the nucleus of MDA-MB-231 cells and a significant reduction in their invasiveness. Furthermore, I discovered that CHD7, when present in the nucleus, re-activates CDH1/E-cadherin transcription through reducing the nucleosome density of its promoter. CDH1/E-cadherin is a well-known BC tumor suppressor gene. My data collectively suggest that retaining CHD7 in the nucleus may serve as an effective therapeutic strategy to inhibit BC metastasis.

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Math : Science : Technology
Regional Finalist

Names: Abhishek Mohan
High School: Texas Academy of Mathematics and Science
Mentor: Dr. Mohammad Omary
Project Title: Identification of a Polymeric Silver(I)-Based Protein Corona Biointerface for Versatile Delivery of Targeted Nanotherapeutics *in Vitro*

The lack of biological adaptability within current nanoparticle (NP) delivery systems and minimal understanding of the protein corona formation have introduced growing concerns regarding the clinical utility of targeted therapeutics. At present, no NP system exists that effectively minimizes disparity of *in vitro-in vivo* correlations while allowing for diversified delivery integration. In this study, chemistry-driven methods were used to investigate characteristic NP changes within diverse physiological conditions and accordingly refine the corona interface for potential *in vivo* versatility. By synthesizing silver(I)-based NPs stabilized by polyacrylic acid (PAA) via photochemical activation, I have identified a biointerface that provides an adaptable framework for objective-oriented therapeutic delivery. UV-Vis, DLS, and ZP characterization methodologies were primarily used to investigate optical, size/dispersity, and electrophoretic NP properties in diverse biological media. A hydrodynamic radii range of 26-30 nanometers was established and the thermodynamic phase transition during NP polymerization was refined, preventing agglomeration and preserving electrochemical equilibrium, respectively. The derived electrophoretic mobility value of -5 μmcm/Vs substantiated anionic persistence, reinforcing biocompatibility and circulation capacity. Consistent corona formation in low, neutral, and high environmental gradients also established conditional adaptability. Hence, this biointerface is an innovative and promising delivery mechanism that provides a versatile framework for future nanotherapeutic technologies.

Siemens Competition
Math : Science : Technology
Regional Finalist

Name: George Wang
High School: Oklahoma School of Science and Mathematics
Mentor: Dr. Bin Wang, Dr. A. K. Fazlur Rahman
Project Title: *Ab Initio* Calculations of Possible Hypercarbon in Ionic Hydrocarbon Compounds and Prediction of Stable Pyramidal Tropylium Trication with Heptacoordinate Carbon

Ionic carbon compounds that contain hypercarbon atoms, which bond to five or more atoms, are important intermediates in chemical synthesis. Extensive investigations have identified the ionic hydrocarbon compounds that contain a pentacoordinate or hexacoordinate hypercarbon atom, such as the pentagonal-pyramidal hexamethylbenzene, $C_6(CH_3)_6^{2+}$, in which a carbon atom is bonded to six neighboring atoms. However, the search for ionic hydrocarbon compounds that contain higher-coordinate carbon, including heptacoordinate and octacoordinate carbon, remains elusive. In this project, we performed *ab initio* density functional calculations, through which we explored the possibility of seven-coordinate and eight-coordinate hypercarbon atoms in ionic hydrocarbon compounds. Our calculations show that the three-dimensional hexagonal pyramidal configuration of tropylium trication, $(C_7H_7)^{3+}$, in which a carbon atom is bonded to seven neighboring atoms, is a stable structure. We therefore make a theoretical prediction that heptacoordinate carbon can be found in the ionic hydrocarbon compound of tropylium trication. On the other hand, the pyramidal configurations of ionic C_8H_8 compounds, which contain an octacoordinate carbon atom, are shown to be unstable. In addition, our calculations show that a previously proposed pyramidal trication, $C_7(CH_3)_7^{3+}$, which would involve heptacoordinate carbon, is an unstable configuration.

Siemens Competition
Math : Science : Technology
Regional Finalist

Names: Michael Ma
High School: Plano West Senior High School
Mentor: William Kuszmaul
Project Title: New Results on Permutation Pattern-Replacement with a Generalization of Erdös-Szekeres

In this paper we study permutation pattern-replacement equivalences. Given a set of patterns we define an equivalence relation on S_n through pattern replacement similar to that of the Knuth relation. We are interested in the number of nontrivial equivalence classes formed on S_n.

We generalize the celebrated Erdös-Szekeres Theorem for permutation pattern avoidance to a new result for permutation pattern-replacement. In particular, we show that under the $\{123\cdots k, k\cdots 321\}$-equivalence, all permutations in S_n are equivalent up to parity when $n \geq \Omega(k^2)$.

The first infinite family of pattern-replacement equivalences to be studied were the rotational equivalences. They proved that rotational equivalences always yield either one or two nontrivial equivalence classes in S_n, and conjectured that the number of nontrivial classes depended only on the rotational equivalence rather than on n. We present a counterexample to their conjecture, and collect extensive computer data allowing us to pose a more refined conjecture. We also prove a partial version of the result.

Finally, we computationally analyze the pattern-replacement equivalences given by sets of pairs of patterns of length four. We then focus on three cases, in which the number of nontrivial equivalence classes matches an OEIS sequence. For two of these we present full proofs of the enumeration and for the final we suggest a method of proof.

Siemens Competition
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Regional Finalist

Names: Charles Hutchison
High School: St. Andrew's Episcopal School
Mentor: Dr. Udayan Mohanty
Project Title: Kinetics and Thermodynamics of Deeply-Supercooled Liquids

The relaxation time of a supercooled glass-forming liquid, which is the time it takes for a local region affected by a thermal fluctuation to return to equilibrium, exhibits complex nonlinear temperature dependence. This dependence can be quantified through the configurational entropy of the system, which is the component of entropy that depends only on the accessible positions and not the vibrational states of the molecules in the liquid. The configurational entropy fraction is an important quantity that controls much of the system's behavior near the glass transition temperature. In this paper, we developed an analytical expression for the fraction of entropy that is configurational at the glass transition temperature. Additionally, we extend the standard Adam-Gibbs model of relaxation in supercooled liquids to include external electric field effects and structurally inhomogeneous fluctuations, allowing for the electric field-induced changes in entropy, relaxation time, and mean fluctuation to be modeled. This work provides insight into the open problem of supercooled liquid kinetics, which are important to understand for the use of supercooled liquids and glasses in many industrial applications.

Siemens Competition
Math : Science : Technology
Regional Finalist

Names: Kshitij Sachan and Yesh Doctor
High School: Plano East Senior High School
Mentor: Leonidas Bleris
Project Title: Site-Specific Integration of Large DNA Fragments: Evaluating and Redesigning Genome Editing Systems

A major bottleneck of genome editing today is the tradeoff between the size of the integrated fragment and the ability to control where it is integrated. Currently, there are no techniques to reliably integrate sequences greater than few thousand base pairs in precise locations. PiggyBac transposase (PBase) is an enzyme capable of transposing mobile genetic elements of up to 200 kb. However, PBase integrates randomly into the genome, resulting in a lack of specificity. To address this issue, we introduce a novel technology for genomic insertion, achieving site-specific integration of fragments larger than previously possible. First, we established PBase mediated integration as a safe and viable technique by demonstrating no cytotoxicity upon insertion. Then, we fused PBase to a deactivated Cas9 (CRISPR-based programmable DNA-binding) to specifically direct PBase integration. This fusion was successful at targeting and displacing a red fluorescent protein gene with another genetic cassette. We show 38% increased on-target integrations as compared to WT PBase. We believe the ability to specifically integrate large DNA fragments will have a transformative impact on multiple fields, with applications such as the bioproduction of pharmaceuticals and fuels, correcting mutated genes, creating vaccine libraries, and storing data on DNA.

Siemens Competition
Math : Science : Technology
Regional Finalist

Names: Sahil Patel and Steven Sun
High School: Texas Academy of Mathematics and Science
Mentor: Dr. Carlos Ordonez
Project Title: Design and Simulation of a Novel Concentric Cone Antihydrogen Gravity Experiment

Antimatter's gravitational properties have long intrigued and eluded physicists. However, experimental attempts so far have largely proven unsuccessful, as current collaborations rely heavily on large numbers of antiatoms and extremely low temperatures. We propose a simple design of an apparatus of concentric cones surrounding a point source of antihydrogen within a cylindrical bounding chamber. Through 14 iterative optimizations in which cones are sequentially added, we defined a final optimal configuration which balances the increased complexity of additional cones with their respective increase in the probability of detecting antiatom annihilations; our design's final configuration detects an annihilation every 1357 antiatoms at a temperature 4 K, a probability higher than our laboratory's previous results by a factor of approximately 74 and a temperature much greater than what is used in experiments by other collaborations. Our novel antihydrogen gravity experiment demonstrates considerable promise of experimental feasibility and therefore the potential to revolutionize the field of physics and further our understanding of the universe itself.

Siemens Competition
Math : Science : Technology
Regional Finalist

Names: Cal Rothkrug, David Yue
High School: St. Mark's School of Texas, Texas Academy of Mathematics & Science
Mentor: Masih Tajik Asl
Project Title: Innovative High-Performance Polymer-Blended Mixed-Matrix Membranes (PB-MMMs) with Heterogenous Triadic Compatibilizers—Small Organic Molecules, Metal Organic Frameworks, and Carbon Nanotubes—for Effective Gas Separation

We have created an innovative gas-separation membrane by combining inorganic membranes with polymeric membranes. Furthermore, we blended a highly selective polymer (polybenzimidazole) with a highly permeable polymer (6FDA-Durene-DABA) for matrices of our membrane to create a novel polymer-blended mixed-matrix membrane (PB-MMM) with significantly improved gas-separation properties. Moreover, our research pioneered the usage of triad-compatibilizers—the small organic molecule 2-methylimidazole, the metal-organic framework zeolitic-imidazolate framework-7 (ZIF-7), and functionalized carbon nanotubes—to improve the mechanical strength as well as the gas permeability and selectivity of the membrane. Characterization and testing showed that, compared to non-compatibilized membranes, our triad compatibilized membrane (6FDA-Durene-DABA:PBI+10%2MI+10%ZIF7+10%CNT) had double the Young's Modulus, triple the tensile strength, and an extrapolated onset decomposition temperature 184.89°C higher. Even more remarkably, our high-performance membranes achieved an H_2 permeability and an H_2/CO_2 selectivity 30.87 and 4.02, respectively, times that of non-compatibilized membranes. Our unprecedented approach successfully created gas-separation membranes with robust mechanical stability, and superior permeability and selectivity: our membranes surpassed the Robeson upper bound and reached the commercially attractive region, an achievement never consistently attained in all previous works. Our membrane's success demonstrates high viability for implementation to reduce harmful carbon emissions before they are even released into the atmosphere.

Siemens Competition
Math : Science : Technology
Regional Finalist

Names: Rachel Li, Jainil Sutaria, Chelsea Wang
High School: Spackenkill High School, Poughkeepsie NY, Ardsley High School, Ardsley NY, Fossil Ridge High School, Fort Collins CO
Mentor: Professor Miriam Rafailovich
Project Title: *Synthesizing and Characterizing Novel Gelatin and Pluronic® F127 Hybrid Hydrogels as a Barrier Membrane for Guided Bone Regeneration Following Periodontitis*

Periodontitis is the inflammation of gingival tissue and the leading cause of tooth loss. To treat periodontitis, guided bone regeneration (GBR) uses a barrier to separate gingival tissue from bone, allowing osteoblast regeneration; however, current barriers have poor mechanical strength. In this study, we synthesized novel gelatin and Pluronic® F127 hybrid hydrogels with improved mechanical strength and evaluated their performance in vitro as GBR barrier membranes. Rheological analysis revealed a five-fold increase in elastic modulus in hybrid hydrogels compared to pure gelatin. We propose that this improved mechanical strength is attributed to three factors: 1) F127 packed into the gelatin mesh allows the network to resist deformation; 2) hydrogen bonding between PEO blocks of F127 and gelatin strengthens the network; 3) physical crosslinking of F127 due to polymer chain entanglement further strengthens the gel. Hybrid gels greatly surpassed the elastic modulus values predicted by the rubber elasticity theory model. Confocal microscopy performed on hybrid gels plated with human dermal fibroblasts revealed significantly reduced cell attachment compared to pure gelatin. 3D reconstruction from confocal image data confirms that hybrid gels remained impermeable to cells. Our findings suggest that gelatin-F127 hybrid hydrogels are promising biomaterials for GBR barrier membranes in periodontitis treatment.

Siemens Competition
Math : Science : Technology
Regional Finalist

Names: Brandon Chen, Andrew Lu, Claire Zhou
High School: Plano West Senior High School, Westlake High School, Clements High School
Mentor: Dr. Suho Oh
Project Title: Determining Criteria for Positroid Flats

Within the study of discrete mathematics, matroid theory serves as an essential tool to generalize structures found in linear algebra, graph theory, and abstract algebra. Techniques in matroid theory have proven useful in better understanding concepts such as linear independence, graph connectivity, and field extensions. In this paper, we focus on a class of matroids, known as positroids, arriving from totally nonnegative matrices, $k \times n$ matrices ($k \leq n$) such that each $k \times k$ submatrix has nonnegative determinant. These structures hold great combinatorial potential with extensive applications in physics. The
K column indices can also be represented using decorated permutations. Using decorated permutations, our paper formulates a useful description of flats, important structures that encode vector spaces from a certain subspace of the matrix column space. These newfound properties of flats are then used to establish a specific set of criteria for positroid concordancy, a crucial property in which the vector space generated by one positroid is properly contained in the other vector space.