THE QUARK

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Mobile Maladies

By Akash Maheshwari

Have you ever been sick before? The answer for nearly all people is "yes." Bacteria, fungi, parasites and viruses are all microscopic particles that possess the ability to infect and negatively affect the health of humans. But how exactly are these microbes transferred between people?

Most diseases are transferred through water droplets expelled from an infected individual primarily by sneezing and coughing. Analysis of the physics behind these two phenomena is fascinating and provides insight into the mechanism by which diseases spread. Sneezing, also known as sternutation in the medical community, is the propulsion of air and mucous from the noise as a result of irritation of the epithelial lining of the nasal cavity. This involuntary action has developed as a way for the body to expel irritants in the nose. However, this expulsion inevitably releases germs into the environment directly outside the person; up to 100,000 droplets can be released from a single sneeze! These droplets are expelled at speeds of up to 100 miles per hour and can easily travel around a closed room. According to fluid dynamicist Lydia Bourouiba at MIT, these droplets can travel up to 8 meters away from the person who sneezed. Each droplet expelled will follow a unique path as they diffuse through the air. Just as perfume molecules diffuse through the air in random Brownian motion, these droplets will randomly collide with air molecules and travel along very different paths. This random movement makes it difficult to determine where every droplet will end up. Further consider the effect of a ceiling fan or recirculation of air by an air conditioning unit on the motion of pathogenic droplets. It becomes clear that these pathogen-containing droplets of water

Contents

About The Quark

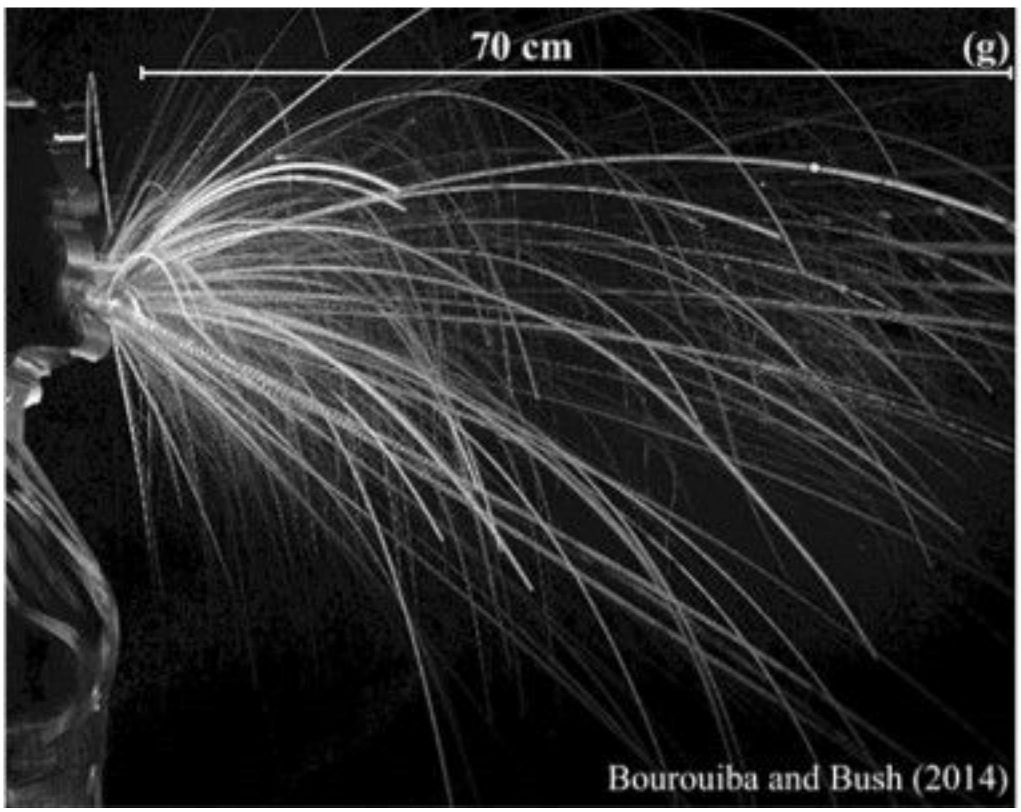
The Quark is a monthly newsletter produced by the Public Relations Committee of the Texas Tech chapter of the Society of Physics Students (SPS). Our goal is to help new students become more familiar with the Physics Department and provide returning students more insight on aspects of the department they might not have been aware about.

If you have any questions about The Quark or SPS, you can email our Public Relations Officer Rob Chambers at Robert.Chambers@ttu.edu .

can be distributed around a closed space rather quickly.

Even though the transmission of these droplets from infected individuals seems very concerning, simple adjustments to our behaviors prove to be very effective. For instance, hand washing is perhaps the most important and effective action people can perform to drastically reduce their risk for infections of many diseases. As Harvard Medical School reported, washing hands thoroughly with soap and water for 15 seconds is effective at decreasing bacterial counts by 90% while washing hands for 30 seconds reduces bacterial counts by an astonishing 99.9%. Soap is an amphipathic substance that forms bubble-like micelles that can capture and remove many different microbes from the skin. After hand washing, be sure to thoroughly dry your hands for another 20 seconds since wet hands are much more effective at spreading diseases. Removing potential pathogens from the hands is especially important because people use their hands to eat food, open doors, shake hands with others, and infect other objects. Therefore, diligent hand washing is one of the best ways to avoid becoming sick. Maintaining a healthy diet, exercising regularly and receiving vaccines are other ways to reduce the risk of illness.

So next time you are sick, be sure to cover your sneeze and cough and wash your hands!



Measurement of trajectory of droplets from sneezes and coughs

Professor of the Month: Dr. Wade DeGottardi

By Samuel Cano

Dr. Wade DeGottardi is a Condensed Matter Theorist hailing from Northern California. As a child, his grandfather, who worked as an electrical engineer, taught him the basics of electricity and magnetism. He was fascinated by his grandfather's deep intuitive understanding of the subject despite not having a college degree or any of the formal training. Dr. DeGottardi discovered his love for Physics in college after his first Physics course, despite initially enrolling as a Chemistry major. He went on his to earn his Bachelor of Science in Physics from Stanford University. Afterwards, he was hired to work for Kaplan, a test prep company, doing tutoring and teacher training. After eight years at Kaplan he decided to go to back to graduate school with the intention of studying Physics Education at the University of Illinois Urbana-Champaign. After a semester of colloquia, he quickly learned he had interest in Condensed Matter Physics. As part of the program he was able to to spend a summer working alongside a collaborator at the Indian Institute of Science in Bengaluru, something he never envisioned himself doing. Dr. DeGottardi completed his Ph.D. in six years and accepted a Postdoctoral research position at Argonne National Laboratory, which is operated by the University of Chicago. There he studied majorana fermions and the hydrodynamics of strongly correlated electron systems. After three years at Argonne, Dr. DeGottardi accepted a second Postdoctoral research position at University of Maryland's Joint Quantum Institute and IREAP (Institute for Research in Electronics and Applied Physics). From there he secured a job at Northrop Grumman in Baltimore researching super conducting circuits and quantum information. Here he was able to be more actively involved in applied research, and he had a lot more access to advanced laboratory equipment.

During all of this, Dr. DeGottardi continued to think about various side projects from his days as a Ph.D. student that he simply could not let go of. Often, he was juggling working 80-hour weeks while still putting time into these various projects, something he was glad he did now that he can work on them as a professor. After his time in industry, Dr. DeGottardi began looking for teaching and research positions in academia. Interestingly enough, Texas Tech was looking for a theorist who had industry or government experience. Dr. DeGottardi, having both, felt like he was a great match for the position. This semester Dr. DeGottardi is teaching Electricity and Magnetism 1. Outside of class, he is preparing the direction of his research and thinking about how to effectively involve undergraduate and graduate students in engaging projects that they can learn from and contribute to.

Dr. DeGottardi remembers his undergraduate Quantum Mechanics course distinctly as being one of the most grueling classes, simply calling it a "source of stress". Retrospectively, he is glad he put the time in to succeed in this course and says he did not realize the true impact it had on him until he reached graduate school. For new physics students, Dr. DeGottardi wants to stress the importance of losing the fear of acknowledging that it is okay to be lost. He went onto to say, "I missed out on a lot of opportunities just to avoid the embarrassment of people thinking you don't know something" and continued to emphasize the importance of overcoming that natural embarrassment and asking questions in class for an undergrad's development as a student, scientist, and person. His last year of undergraduate was very stressful in general, and he wants current physics students that they are not alone in their endeavors. Dr. DeGottardi also wants to let students know that it's okay to take time off, for him that break between undergraduate and graduate school was crucial for his motivation and ended up making him a much better student when he returned for his Ph.D. Nowadays Dr. DeGottardi spends his leisure time bird watching at nearby lakes and watching horror movies. He admits that, as a scientist, it is very easy for physics to be both his job and his hobby. Dr. DeGottardi is excited to be at Texas Tech and is currently working on building his research group. Toward that end, he wants any undergraduate or graduate students interested in working on research and learning about problems in the field to reach out to him and become part of his group.

Vesicle Fusion: A Mathematical Analysis

By William Kariampuzha

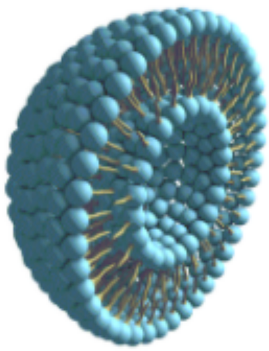
Rarely are we offered the opportunity to investigate the physics of what occurs inside our bodies trillions of times every second. As a student of biology, I am fascinated by our physiology, but I always yearn for a fundamental physical explanation. In a bacterial physiology class, Dr. San Francisco, Interim Dean of the College of Arts and Sciences, captured our imaginations with bacterial proteins oscillating between the two poles of a bacillus - keeping time like a metronome [3]. I was bothered by how I was simply told in all my classes that vesicles fuse with each other and with the cytoplasmic membrane. I was never given a detailed explanation as to how so I decided to try to figure it out with the time-tested tool of physicists: mathematics.

As a refresher, a vesicle is a spherical object composed of two layers of phospholipids arranged back-to-back (for our purposes, closely modeled by a space-filling cylinder) that encompass water and other cellular materials for transport. Vesicles are the truckers of our body. From neurotransmitters that are being released as you read and process this sentence, to insulin transporters that get activated as you finish up your sandwich, they store and transport things all over our body. In fact, disregarding notable composition differences, a cell is essentially a souped-up vesicle with the cytoplasmic membrane being analogous to the vesicle membrane.

To understand how vesicle fusion occurs, we will make a few simplifying assumptions. Here we will assume a uniform spherical vesicle of radius r, a phospholipid of length p, constant phospholipid density, that all phosphatidyl units (a single phospholipid) are the same, and that the two fusing vesicles are exactly the same. This allows us to derive the following formulas:

$$\text{Volume of Vesicle} = \tfrac{4}{3}\pi r^{3}$$

$$\text{Volume of Membrane} = \tfrac{4}{3}\pi(r+2p)^{3} - \tfrac{4}{3}\pi r^{3} = \tfrac{8}{3}\pi p(3r^{2}+6rp+4p^{2})$$



Vesicle Cross-Section

This also means that we can derive the surface area of a vesicle:

$$\text{Outer Surface Area} = 4\pi(r+2p)^{2}$$

$$\text{Inner Surface Area} = 4\pi r^{2}$$

Therefore, if the phospholipids have isometric surface area (when viewed down their axis, looking at the heads) and assuming an even, tight distribution and no membrane invagination, then there are more phospholipids on the outside than on the inside.

Wow! We learned something new about vesicles. However this is super boring - things get much more interesting when we apply the principle of conservation of mass and volume to vesicles. This is interesting because we can take a walk down two different roads: constant membrane mass or constant enclosed mass. By extension, this assumes constant volume of membranes and enclosed area if we assume constant maximum density (actual phospholipid density is influenced heavily by temperature and composition so in this thought experiment we will assume constancy in both variables).

If we assume constant enclosed volume of two identical vesicles of radius r1 we arrive at

$$\text{Total Volume of Two Vesicles} = \tfrac{8}{3}\pi r_{1}^{3}$$

Fusing them together yields a single vesicle of radius r2 which allows us to solve the volume of the newly fused vesicle membrane, using the aforementioned formula:

$$\text{Radius of Fused Vesicle} = \tfrac{4}{3}\pi r_{2}^{3} = \tfrac{8}{3}\pi r_{1}^{3} \rightarrow r_{2} = r_{1}\sqrt[3]{2}$$

$$\text{Fused Membrane Volume} = \tfrac{4}{3}\pi(r\sqrt[3]{2}+2p)^{3} - \tfrac{4}{3}\pi(r\sqrt[3]{2})^{3} = \tfrac{8}{3}\pi p(3r^{2}\sqrt[3]{4}+6rp\sqrt[3]{2}+4p^{2})$$

So, does fused membrane volume equal twice the amount of original membrane volume?

$$\tfrac{8}{3}\pi p(3r^{2}\sqrt[3]{4}+6rp\sqrt[3]{2}+4p^{2}) = 2[\tfrac{8}{3}\pi p(3r^{2}+6rp+4p^{2})]$$

If we plug in r = 100, p = 1, we can see that the Fused Membrane Volume is approximately 512,775 units3, while the two of the original membranes approximately equals 405,324 units3. So no, fused membrane volume does not equal twice the amount of original membrane volume. Moreover, if we consider a significantly large ratio of radius length to phospholipid length, this equation shows that 21% of phospholipids are lost.

So what happens to the phospholipids that are lost? If the vesicle stays the same volume, are the additional phospholipids condensed? Do membrane invaginations explain what happens to the extra phospholipids?

The physics gets much more interesting when we consider constant membrane mass. As before, our assumption of constant membrane density, yields a constant membrane volume where phospholipids are not lost.

Using the aforementioned membrane formula,

$$\text{Original Membrane Volume} = \tfrac{8}{3}\pi p(3r^2 + 6rp + 4p^2)$$
$$\text{Fused Membrane Volume} = 2(\text{Original Membrane Volume}) = \tfrac{16}{3}\pi p(3r^2 + 6rp + 4p^2)$$

With this equation, we can solve for the new radius (R) of the enclosed region:

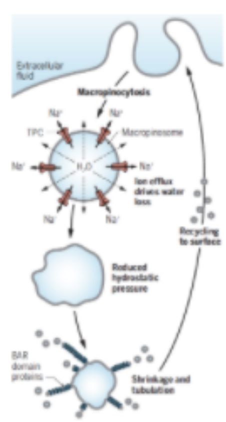
$$\textit{Fused Membrane Volume} = \textit{Membrane Volume of Sphere of radius } R$$
$$\tfrac{16}{3}\pi p(3r^2 + 6rp + 4p^2) = \tfrac{4}{3}\pi(R + 2p)^3 - \tfrac{4}{3}\pi R^3$$
$$\sqrt{\frac{6r^2 + 12rp + 4p^2}{3}} = R$$

Using this radius, we can see that the new volume of enclosed region is

$$V = \tfrac{4}{3}\pi R^3$$
$$V = \tfrac{4}{3}\pi\left(\frac{6r^2 + 12rp + 4p^2}{3}\right)^{\frac{3}{2}}$$

When plugging in the same values as our previous comparison, we find a 183% increase in enclosed volume if the phospholipids do not detach from the vesicle. So what is happening? Does more material enter the vesicle?

Like most biologically based systems - the answer is more complex than simply one or the other. In the case of a vesicle's phospholipid/enclosed volume ratio being higher than necessary - which is what we are looking at after fusion - the phospholipids actually can be lost! They could pinch off and form little tube-fingers with the help of some BAR proteins, which equalizes the ratio such that the phospholipid membrane tightens around the enclosed package. [2]



Shrinking vesicles [2]

However, as is shown in the figure, when the enclosed volume/phospholipid ratio is high, the vesicle actually loses liquid until it is flaccid and then gets equalized with phospholipid loss. Additionally, looking at conservation of mass in the non-growing cell as a whole, "the phospholipids that create the transport vesicles following endocytosis of cargoes from the plasma membrane come from the plasma membrane itself. In addition, the release of secreted hormones (e.g., insulin) comes from secretory vesicles that bud off from the Golgi apparatus containing the secretory cargo (i.e., the stuff inside the lumen of the vesicle, like the protein insulin) and then fuse with the plasma membrane, thereby delivering the phospholipids that compose the secretory vesicle to the plasma membrane. So, if the cell volume defined by the area encircled by the plasma membrane is constant, what it really means is that losses of phospholipids from the plasma membrane caused by endo- and phagocytosis are being matched closely by phospholipid additions caused by exocytosis," according to Dr. Nathan Collie [1].

Hopefully through this simple thought experiment, you have gained a small appreciation of the physical acrobatics that our cells go through trillions of times a second. However, I hope even more so, that you have gained an appreciation of how to apply simple physical principles and mathematical tools to yield exciting insights and appreciation for how the world, and your body, works.

Student Spotlight: Robert Chambers

By Victor Ethan Bradley

Understanding the unknown has always been a fascination to Robert Chambers. After his AP physics class in high school, he realized the universe was governed by laws much more abstract than he had previously thought and this opened him up to a whole new world. Robert also worked on his high school's robotics team, helping the team to reach not only the state championship but the world championships in his senior year. This experience cemented the idea that he wanted to work in STEM, and that led him to Texas Tech due to its world-class physics research and scholarship opportunities.

During his time at Texas Tech, Robert has been the recipient of several scholarships including the National Merit Finalist Award, Menzel Memorial award, and the Schmidt Physics and Engineering in Physics Scholarship. He is currently participating in research with the High Energy Physics group on Muon Tomography under Dr. Shuichi Kunori, where he is working on constructing a detector that creates 3D images of structures using Muons produced in the atmosphere. This includes working on integrating Field Programmable Data Arrays (FPGA's) into the data handling system to further streamline and refine the process. Robert is also the Public Relations Officer for the Society of Physics Students at Texas Tech. His responsibilities would normally include planning and managing outreach events in the Lubbock community, as well as leading production of the Quark newsletter. However, with the current global pandemic, his responsibilities have been limited to only managing the newsletter.

Outside of school, Robert's hobbies include hiking, playing video and board games, and reading. He also has a passion for learning languages, which has inspired him to pursue a minor in German. Germans have a very pragmatic and logical culture, which appealed to him as a STEM major. Working overseas has always been a dream of his, and being able to speak German is a big step towards working in Germany, or anywhere in the European Union.

After he graduates from Texas Tech, he plans to pursue a Ph.D. and hopes to have a career in Physics research. He has a fascination with quantum mechanics and aspires to work in that field in the future. He sees quantum and high-energy physics as the cutting edge of physics research, where he can make meaningful contributions to physics as a whole. Ideally, Robert wants to work at the CERN laboratory in Geneva, Switzerland, because it represents one of the biggest and most advanced experiments in physics right now. His advice to new physics students is to "find a field that interests you and stick with it, because passion is as critical as knowledge in a major as demanding as physics. Not enjoying your work is like failing before you even begin."

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[11] https://en.wikipedia.org/wiki/Brownian_motion

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