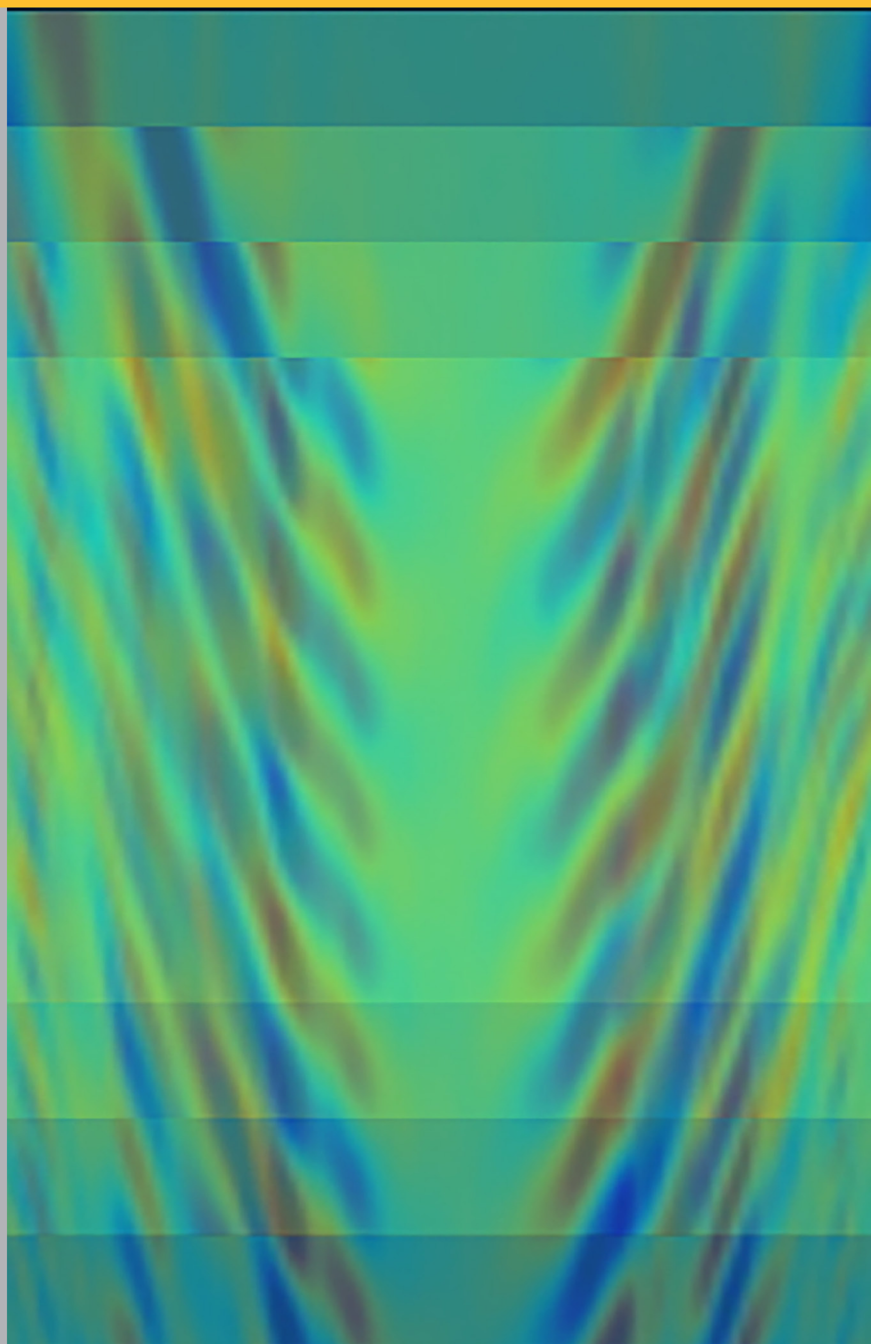
The News and Information Publication of The Society of Rheology
Volume 93 Number 1, July 2024

Rheology Bulletin



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- Rheology in the Biological Sciences
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On the Cover: The formation of thin sheets of high polymeric stress in elasto-inertial turbulence (EIT) acts like a barrier for the flow. Their nested arrangement leads to the emergence of a nested family of wall mode-induced nonlinearly self-sustained traveling waves. This seems to be the dominant dynamics of elasto-inertial turbulence. Image provided by Manish Kumar and Michael D. Graham (U. Wisconsin, Madison).

The *Rheology Bulletin* is the news and information publication of The Society of Rheology (SoR) and is published yearly in July (in non-pandemic years). Subscription is free with membership in The Society of Rheology. Letters to the editor may be sent to Paulo E. Arratia at *parratia@seas.upenn.edu*

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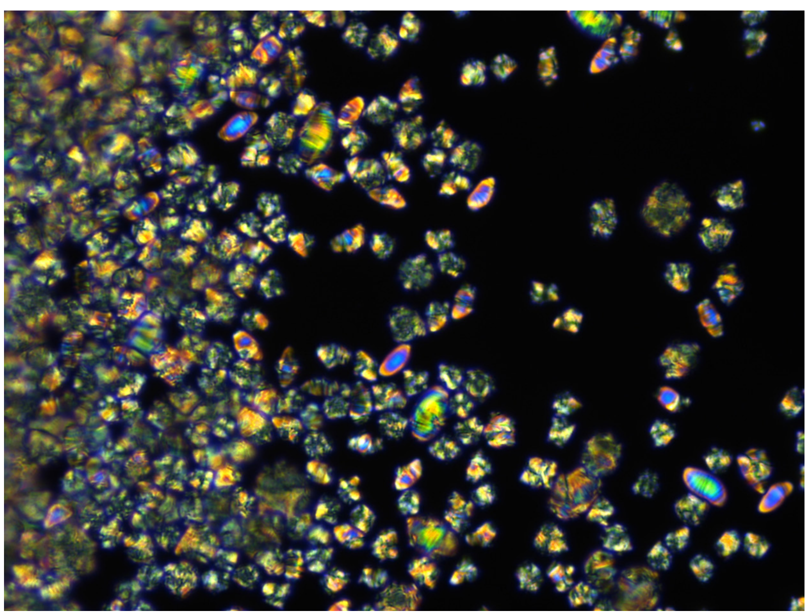


Highly anisotropic liquid crystal elastomer particles capable of shape transformations are used to regulate the rheological properties of a dense suspension. The rich colors under crossed polarized optical microscopy originate from birefringence, indicating that local alignment of liquid crystalline domains within the particles. Image by Chuqiao (Elise) Chen at University of Chicago.

Dear Society of Rheology Members,

As your new President, I would like to take this opportunity to thank you for all that you do for the Society and for all of the great work that you have done and continue to do to advance the science of rheology. As an all-volunteer society, the strength of our Society is you, our members. Because of you, I am happy to report that our Society is in great shape today and for the foreseeable future.

I would like to thank Anne Grillet for her steadfast leadership of the Society over the last two years and her continued contributions and mentoring in her role as past-president. I also would like to welcome Jeff Morris who joins the Society leadership team as Vice President and Lisa Biswal who is our new Treasurer. Finally, Emanuela Del Gado has graciously agreed to become our new Associate Editor of the Journal of Rheology. I firmly believe that the Society is in good hands moving forward.

Over the course of the year, we will continue to execute on our mission to expand the knowledge and practice of rheology through hosting of our annual meetings, the publication of the Journal of Rheology, our education, outreach and mentoring activities, and through the fresh ideas that you submit to the Rheology Venture Fund. In addition to several ongoing projects, this year's RVF winners include a project by Olfa D'Angelo, Thomas Voigtmann and Norman J. Wagner entitled "Space Rheology Initiative" designed to raise awareness of space-related research opportunities in rheology and a project by Matt Helgeson, Reza Foudazi, Arif Nelson, Maggie Qi, Helen Joyner and Jim Gilchrist entitled "Rheology Academy – an Online Education Platform for the Society of Rheology" designed to develop a wide range of rheology related virtual courses to be hosted on our website.

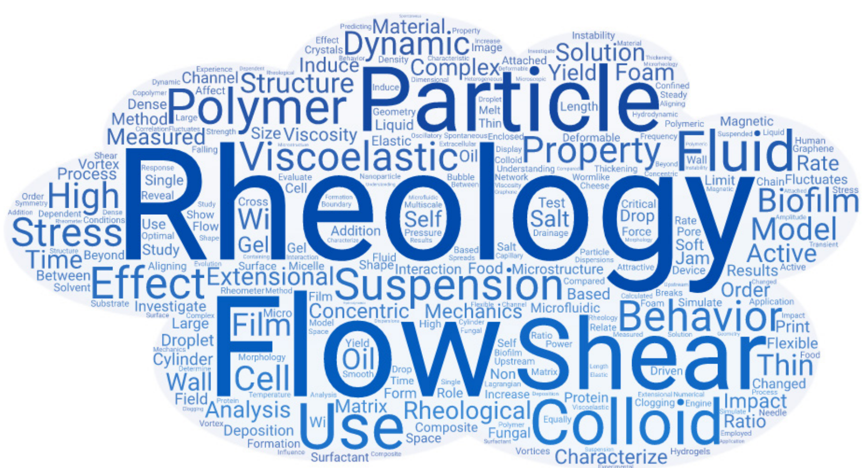
Last summer's International Congress of Rheology in Athens was a great success in an amazing location. Our gracious hosts, Dimitris Vlassopoulos and Moshe Gottlieb really put on an incredible conference that truly showcased the wealth and diversity of rheological research being performed around the world. With nearly 1000 participants from approximately 40 countries and almost 600 talks, it is clear that the science of rheology remains vibrant.

This year's Society of Rheology Annual Meeting will take place in Austin, Texas and will be hosted by Roger Bonnecaze. I hope that you will join me there to celebrate our newest Bingham Medalist, Mike Graham, our most recent Metzner Awardee, Lilian Hsiao, and our 2024 class of Fellows. With nearly 400 abstracts already submitted, Austin looks to continue the recent trend of well-attended annual meetings that started with Chicago and I hope will continue in Santa Fe in 2025, Boston in 2026 and beyond. The technical program promises to be exciting, capturing both the depth and breadth of our Society. There will be two short courses, one on Large Amplitude Oscillatory Shear (LAOS) and the other on Automated Rheology, a K12 outreach event at a local children's museum called the Thinkery, the student-industry forum and the Rheology Research Symposium (RRS).

This year we have begun planning in earnest for our centennial celebration to be held in Washington D.C. in 2029. Peter Olmstead has agreed to be the local organizer and, with the help of the APS meeting planners, we are actively looking for the perfect location for our centennial meeting. As part of the centennial celebration we will be focusing on collecting and documenting the history of the Society. At the 2024 meeting in Austin, historians from AIP will be in attendance to collect some detailed oral histories and short anecdotes on what the Society means to us. These oral histories along with those already collected by our Society's Historian, Gareth McKinley, will be hosted on a newly redesigned website capable of also hosting the Rheology Academy.

The future of the Society is bright. I look forward to a great year for the Society. See you in Austin.

Regards,
Jonathan P. Rothstein,
President of The Society of Rheology



Report from Athens, Greece: ICR 2023

The nineteenth (IΘ') International Congress on Rheology (ICR2023) was held in Athens, Greece from July 31 to August 4, 2023. This event marked the first time that both the Society of Rheology (SoR) and the European Society of Rheology (ESR) held their annual meetings in conjunction with the ICR. The technical program committee was chaired by Jan Vermant, while Dimitris Vlassopoulos and Moshe Gottlieb were in charge of the local arrangements with assistance from Erasmus, a Professional Congress Organizer.

The Athenaum Intercontinental served as the venue for the meeting, conveniently located near the center of Athens. The conference facilities spanned three floors. Attendees also enjoyed a breathtaking view of the Parthenon, a key landmark of Western civilization, from the hotel's terrace.

Two short courses were offered on 29 and 30 July. The first was on *Rheology of living systems*, taught by Gerry Fuller (Stanford Univ.) and Pietro Cicuta (Univ. of Cambridge) and attracted 34 attendees. The second was on *Advances in rheometric methods and rheological data analysis*, taught by Gareth McKinley (MIT), Randy Ewoldt (UIUC) and Sebastien Manneville (ENS Lyon) and attracted 110 attendees.

The conference started on the evening of the 30^{th} of July with a total of 954 participants registered (321 students, 34 exhibitors) and 85 accompanying persons, arriving from 38 countries. The two largest constituencies were those of USA (163) and France (96). The technical program included 15 symposia. The oral program was developed in 13 tracks and a total of 122 sessions and 573 presentations.

Traditional topics in rheology were interwoven with recent developments. Except for Wednesday, each morning and afternoon segment began with plenary talks. These included the Weissenberg and Bingham lectures, delivered by Jeff Morris and Pier Luca Maffettone, respectively, and concluded with a forward-looking plenary session. The 25 keynote presentations were distributed among the symposia and included the Oldroyd, Metzner, and JNNFM Walters prize lectures, given by Duncan Hewitt, Sujit Datta, and Stylianos Varchanis, respectively. The memory of Professor Tom C. B. McLeish was honored by some of his colleagues and collaborators in a special memorial session. Wednesday morning was solely dedicated to the plenary poster session with 293 presentations.

Dimitris Vlassopoulos, Chair of the very successful (and fun) ICR 2023, addressing attendees.

The diverse social program included several highlights, beginning with a welcome reception at the conference hotel on Sunday, July 30. Participants enjoyed a private visit to the Acropolis museum followed by a reception at the nearby Athens tennis club. The Wednesday afternoon excursions offered options ranging from the nearby island of Aegina to cape Sounion, Delphi antiquities, ancient Korinth and various sites and museums in the city of Athens. The conference banquet, held outdoors by the beach, offered stunning views of

Saronikos Bay and a beautiful sunset. During the banquet, the ESR and SoR awards and fellowships were presented. The evening concluded with a dance party, giving new meaning to the phrase "πάντα ῥεῖ". At the closing ceremony on Friday afternoon, the poster awards were announced and distributed. The organizers are pleased with the positive feedback from attendees and are grateful to the 36 sponsors and exhibitors, as well as to Erasmus, who contributed to the success of the meeting.

Moshe Gottlieb, Jan Vermant, Dimitris Vlassopoulos


Bingham Medalist Jeff Morris (left) and Metzner Award winner Sujit Datta (right) receiving their accolades from the Society of Rheology.

Diversity, Equity, & Inclusion Efforts

By Katie Weigandt

The Society of Rheology Diversity, Equity, and Inclusion (DEI) Committee is working to develop policies, practices and programs that will lead to a diverse and inclusive community of rheologists. The Rheology Research Symposium (RRS) is a flagship program led by the committee. It was originally sponsored by the AIP Venture Capital Fund and as of 2022 is now fully funded by the SoR. The RRS is designed to welcome up-and-coming student rheologists into the society with mentoring and professional development programming during the weekend leading up to the annual SoR meeting. At the Chicago meeting we welcomed 26 graduate students from around the world to participate in the 3rd annual RRS. The students were assigned to small groups with mentors from academia, government labs and industry and participated in programming that included career planning, overcoming career obstacles, networking, scientific communication with the public, and an introduction to the SoR. The next RRS will take place in conjunction with the 95th Annual Meeting in Austin Texas in October of 2024. We are grateful for the outstanding support of the SoR members who have volunteered as mentors or panelists, and we are looking forward to welcoming 24 student members to the 4th annual RRS.

3rd Annual RRS Group Picture

In 2023 the SoR updated its official Code of Conduct and Anti-Harassment Policy to define a process for reporting and responding to complaints. It is the goal of the society that every SoR-sponsored event be welcoming to all participants and free from any form of discrimination, harassment, or retaliation. This is achievable if we all work together to create a collegial, inclusive, and professional environment by acting respectfully toward our colleagues, whether engaging in lively scientific debate or social conversations. At the 2022 SoR meeting in Chicago we piloted new formalized in-person and online harassment reporting processes. The online reporting system is facilitated in partnership with the AIP through AIPs Navex EthicsPoint online portal. The deployment of these new reporting mechanisms is a big step forward toward ensuring that our meetings are free from harassing and disruptive behaviors as we can't work to address issues unless they are reported. We hope that everyone who attends our events feels respected and valued, but if you do encounter behaviors not in line with our code of conduct, please make use of the in person or online reporting processes so that we can address problems as they arise and build an inclusive and welcoming community together.

If you would like to become involved in the DEI efforts of the society or volunteer for a future Rheology Research Symposium please reach out to the DEI committee. Current committee members include Arshiya Bhadu (Penn State, student member), Peter Gilbert (Queen's University), Ali Mohraz (UC Irvine), Susan Muller (UC Berkeley), Kelly Schultz (Purdue University), Maryam Sepehr (Chevron), and Katie Weigandt (NIST, Chair).

Join the Student Slack Channel for the Society of Rheology!

Are you a passionate trainee exploring the fascinating world of rheology? Looking to expand your network and connect with like-minded individuals? Search no further! We proudly present the Society of Rheology's exclusive Student Slack Server, a communication space specifically designed and reserved for students and postdocs in rheology!

By joining the Slack channel, you are expanding your network and opening doors to future opportunities that will shape your career in rheology. Launched in Fall 2021, we currently have 85 active members and counting! During conferences (SoR, AICHE, APS, ACS, and more!), the Slack channel is a communication hub for SoR student members to connect. Join us to forge friendships and professional relationships.

Stay ahead with SoR news with our server! We routinely post announcements about conference deadlines, SoR seminars, and frontier research in rheology fields! Be the first to know about the latest developments in rheology! So join the Slack channel to stay up-to-date with seminar infos, job advertisements and mingle with rheology friends.

SoRStudent
Future flows

Scan the QR code to join us and embark on an unforgettable adventure with fellow rheology enthusiasts worldwide. If you have any questions, don't hesitate to contact your student representatives, Elise Chen (elisechen@uchicago.edu) and Arshiya Bhadu (arshiyabhadu@psu.edu).

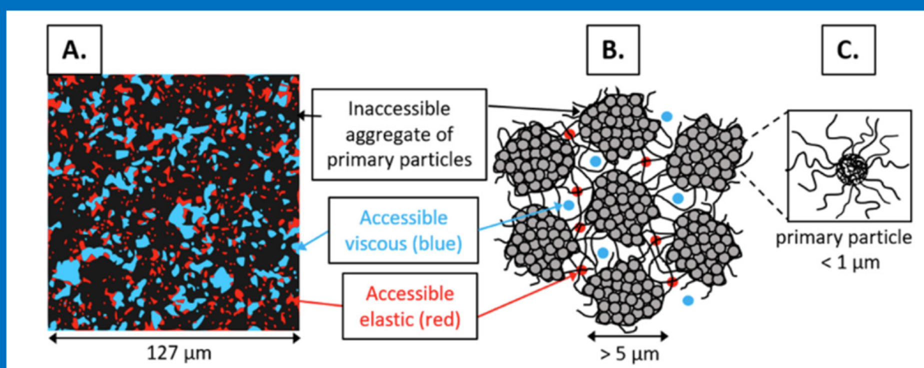
News from the Journal of Rheology

Publication Awards

2024 Award

C. Oelschlaeger, J. Marten, F. Péridont, & N. Willenbacher
Karlsruhe Institute of Technology, Germany

"Imaging of the microstructure of Carbopol dispersions and correlation with their macroelasticity: A micro- and macro-rheological study"
J. Rheo., **66**(4), 1749-760 (2022)



JNNFM-RA-JoR Online Seminar Series returns this fall!

Journal of Non-Newtonian Fluid Mechanics
JOURNAL OF RHEOLOGY®
Rheologica Acta

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- **Latest on rheology research**
- **Featured Articles & Highlights**
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Announcing the 2024 Elected Fellows of the Society of Rheology


Christian Clasen
KU Leuven


Michel Cloitre
CNRS/ESPCI Paris


Albert Co
U. Maine


Brian Edwards
U. Tennessee,
Knoxville


Eric Furst
U. Delaware


Marie-Claude Heuzey
Polytechnique Montreal


Carlos Lopez Barron
Exxon Mobil

Announcing the 2024 Inducted Fellows of the Society of Rheology

Gareth H. McKinley
MIT

Julia A. Kornfield
California Institute of Technology

Norm Wagner
U. Delaware

Michael Rubinstein
Duke University

Michael D. Graham
U. Wisconsin, Madison

Ralph H. Colby
Penn State University

Lilian C. Hsiao
2024 Metzner Award

By Ron Larson

I am delighted to celebrate the awarding of the 2024 Arthur B. Metzner Early Career Award of the Society of Rheology to Lilian C. Hsiao, whose citation reads:

> *For using in situ confocal rheometry to identify microscale structure-property relations of anisotropic colloids during shear flow, and for applying rheological and self-assembly principles to address knowledge gaps in the friction of soft materials, with immediate relevance to emerging technologies in haptic engineering.*

Lilian was born in Hong Kong and moved with her family to Singapore while she was in elementary school. There she gained an interest in science, in particular chemistry and physics. Initially planning to do a Bachelor's degree in Biochemistry at the University of Wisconsin-Madison, she was cajoled by her friends into Chemical Engineering instead. There she encountered Dan Klingenberg in her undergraduate transport class, who taught from the famous text by Bird, Stewart and Lightfoot. Finding transport her favorite subject, she took on an undergraduate research project with Dan on electrorheological fluids. This sparked an interest in experimental rheology, which was fanned into a passion during her Ph.D. work at the University of Michigan with Mike Solomon on colloidal suspensions.

At Michigan, Lilian worked with Solomon and Glotzer to combine confocal microscopy and computational simulations to determine the microstructural basis of stress relaxation in colloidal gels. In this work, Lilian determined the load-bearing portion of the colloidal gel structure by capturing the position and motion of individual particles in the 3D network, and connecting them to linear and nonlinear rheological properties. The resulting highly influential work was published in the Proceedings of the National Academy of Sciences in 2012 and in subsequent papers, including one with Solomon and Furst in the Journal of Rheology (JoR) in 2014. She also examined the structure of assemblies of anisotropic discoidal particles for which both orientation and position need to be mapped, and thereby discovered a preferred orientational order in such assemblies, a result published in Nature Communications.

While still completing her Ph.D., Lilian's adventurous spirit led her into even more novel territory when she introduced controlled roughness into particle-particle interactions. Lilian developed a technique for synthesizing poly(methyl methacrylate) colloids of controllable roughness. Initially frustrated at her inability to find major changes produced in gelation, she raised the particle concentration, and discovered the profound effect that roughness has on shear thickening and the jamming transition. Using both confocal imaging and rheological measurements she found the first truly quantitative relationship between rheology of dense suspensions and particle roughness.

Lilian continued to use microscopy to study the phase behavior of nanoemulsions while she was a postdoctoral scholar with Pat Doyle at MIT. There she met Safa Jamali, with whom she collaborated to illustrate how frictional contacts affect suspension rheology. They used confocal rheology and computer simulations to lay a strong, experimentally-grounded basis for how rotational jamming affects the contact networks found in shear thickening suspensions, which was published in Physical Review Letters and JoR. Like her earlier work on gels, this work broke new ground in the synthesis and characterization of particles of controlled roughness, the imaging of these particles at rest and under flow, and the correlation of these structures with rheological properties. In particular, her 2022 JoR publication reported that rough colloids display unexpected solid-like properties after shear and can retain memory of their previous state, similar to entangled polymer solutions. This memory is highly dependent on the pre-shear protocol and microstructural state of the suspension. While most scientific studies have focused on ideally smooth particles, rough particles are common in industrial practice and are important in jamming, shear thickening, and other problems of great current interest.

Her keen interest in frictional contacts then led Lilian to initiate an experimental program on tribology. This led her into contact with Yon Visell at the University of California Santa Barbara, whose interest in haptic technology led Lilian into the area of tactile materials. This work involves a combination of rheology and tribology to investigate how self-organization of molecules and fluid flow patterns at the interface alters haptic perception. Her group recently developed and validated a theory that predicts the lubricated friction of many patterned polymers, including that of robotic and human hands. Such work has many applications, such as wearable devices, which have gained immense popularity in technologies including augmented reality, electronic skin, and energy harvesting. Another application is hydrogel dressings tailored for pain and healing management, a technology being developed by an NC State startup company for which she is the founding scientist.

In her current work, Lilian and collaborators discovered that amphiphilic molecules migrate to the surface of polymers and form different configurations under shear. This phenomenon provided distinctive changes in the tactile feel as well as the triboelectric performance of polymeric devices coated with these self-assembled amphiphiles. This is the first study that shows how tactile perception and energy harvesting performance can both be tuned by a single C = C bond on a small molecule that self-assembles at the interface, and provides an original and universal physical model for how friction is reduced by changes in the mesostructure of small organic molecules under pressure. Other active areas of research in her group includes the use of external stimuli to study gelation, speeding up and slowing down material dynamics, using interfacial mechanics and iono-tronic systems for haptic sensors, and applying her understanding of colloidal self-assembly to create materials that can be used in capturing contaminants from the environment.

Lilian has a high level of creativity and productivity, with 36 publications in print or accepted for publication, many of which deal with rheology at the microscopic or macroscopic level. Her research has been featured in >80 invited talks and highlighted by multiple awards, including the Camille Dreyfus Teacher-Scholar Award, a Sloan Research Fellowship in Chemistry, the ACS Unilever Award for Outstanding Young Investigator, an NSF CAREER award, and the AAAS Marion Milligan Mason Award.

In addition to her scholarly work, Lilian is actively involved in leadership and planning roles in multiple technical communities including the American Physical Society (APS) Division of Soft Matter, the American Institute of Chemical Engineers (AIChE), the American Chemical Society (ACS) Colloid and Surface Science group, and of course the Society of Rheology (SoR). She has co-organized two national scientific meetings in Raleigh (Society of Rheology 2019 and ACS Colloids 2022), and has contributed significantly to diversity by enhancing the Wikipedia profiles of underrepresented women and minorities in science. Lilian is a vibrant and fun-loving colleague, serious about her science, but gregarious and generous in her friendships. Her cute dog, Tora, can be seen often in her office happily providing companionship to her students and colleagues over rheology discussions.

I and many of my rheological colleagues are proud to have helped in some way Lilian's development into an outstanding rheologist, well deserving of the Arthur B. Metzner Early Career Award of the Society of Rheology.

From:
Ronald G. Larson, Distinguished University Professor, Univ. of Michigan, Ann Arbor, MI, July 16, 2024

Michael D. Graham 2024 Bingham Medalist

by Charles M. Schroeder

Michael D. Graham, Steenbock Professor of Engineering and Harvey D. Spangler Professor in the Department of Chemical and Biological Engineering at the University of Wisconsin-Madison, is the recipient of the 2024 Bingham Medal from the Society of Rheology. Mike's research uses theory and computation to understand the rheology and dynamics of complex fluids over a wide range of length and time scales. His research is distinguished both by the impressive breadth of topics where he has done groundbreaking and influential work and the exceptional quality and strong focus on achieving fundamental mechanistic insight in rheology and fluid dynamics.

Mike received his Ph.D. in chemical engineering from Cornell University in 1992 with the late Paul Steen. Following his Ph.D., Mike was a postdoctoral fellow at the University of Houston (with Dan Luss) and Princeton University (with Yannis Kevrekidis) before starting his independent career as an Assistant Professor in the Department of Chemical and Biological Engineering at the University of Wisconsin-Madison in 1994.

Mike has been recognized with several impressive awards and accolades, including the William Schowalter Lecture Award from the American Institute of Chemical Engineers in 2019 for outstanding accomplishments in theoretical and computational fluid dynamics, the Stanley Corrsin Award from the Division of Fluid Dynamics at the American Physical Society in 2015, a highly prestigious Vannevar Bush Faculty Fellowship from the Department of Defense, several named lectureships at peer institutions, and nearly 200 invited seminars. Mike has a long and dedicated record of service with the Society of Rheology, including serving as President of SoR (2020-2021), Vice President (2018-2019), Chair and Member of the Bingham Medal Committee, Technical Co-Chair of the SoR Annual Meeting in 2007, and several other roles. He previously served as Editor-in-Chief of the *Journal of Non-Newtonian Fluid Mechanics* (2013-2015) and Associate Editor of the *Journal of Fluid Mechanics*, (2005-2012).

Mike's research focuses on two major areas: (1) microscale rheology and dynamics of multiphase and active fluids, and (2) flow instabilities, nonlinear dynamics, and turbulence in Newtonian and complex fluids. In the area of microscale rheology, his work has focused on understanding the dynamics of DNA molecules in microfluidic confinement, the dynamics of blood cells in flow, collective dynamics in bacterial swimming, the dynamics of thin deformable sheets in flow, and the rheology of dilute micellar surfactant solutions. In the area of flow instabilities and turbulence, his work has elucidated complex interactions between rheology and fluid dynamics giving rise to turbulent drag reduction in polymer and surfactant solutions. In all cases, Mike and his research group have made numerous impactful contributions to the field of rheology that have given our community a bevy of new scholarly ideas.

A main focus of Mike's work lies in understanding the microhydrodynamics and rheology of polymer solutions under confinement. Mike's research has been at the forefront of efforts to understand the behavior of DNA and polymers in confined spaces. One of Mike's seminal contributions in this area was the development of a method for coarse-grained Brownian Dynamics simulations of flowing polymer solutions in a confined geometry that accurately accounts for both intramolecular and wall-induced hydrodynamic interactions (HI) (Jendrejack et al., *J. Chem. Phys.*, 2004). This work relied on development of a self-consistent coarse-grained Langevin description of the polymer dynamics, together with a numerical simulation of the flow in the confined geometry that is affected by the motions of polymer segments. Using this groundbreaking method, Mike's group was able to computationally capture experimental observations regarding the migration of flexible polymers away from solid surfaces in dilute solutions. Mike further developed a coarse-grained molecular theory that incorporates both HI and velocity gradient-dependent conformations, leading to new predictions of non-monotonic concentration profiles (Ma and Graham, *Phys. Fluids*, 2005). Subsequent experimental validations have confirmed the accuracy of these predictions, and related work extended these concepts to polymer dynamics in oscillatory flows in microchannels (Chen et al., *Macromolecules*, 2005) and development of an immersed boundary method for Brownian dynamics simulation of DNA and polymer chains in complex geometries (Zhang et al., *J. Chem. Phys.*, 2012). His work in this area has broad implications beyond DNA, with applications in various processes involving confined complex fluids.

In a second area, Mike's work has provided invaluable insights into crucial aspects of blood flow, shedding light on the behavior of blood components and their implications for disease and biological outcomes. The distribution of particles such as white blood cells and platelets during blood flow plays a pivotal role in determining physiological responses. One of the key phenomena Mike investigated involves the margination of blood components (Kumar and Graham, *Phys. Rev. Lett*., 2012; Kumar and Graham, *Soft Matter* 2012), where flexible red blood cells migrate toward the center of blood vessels, leaving a cell-free layer at the vessel wall. In contrast, stiff white blood cells and small platelets preferentially localize near the walls. This phenomenon, known as margination, is critical for physiological responses such as inflammation and hemostasis. Mike's research elucidated the mechanisms underlying margination while further highlighting its significance in the pathophysiology of certain blood disorders (Fay et al., *Proc. Natl. Acad. Sci*., 2016; Cheng et al., *Sci. Adv*. 2023). A notable contribution from Mike's group is the development of a kinetic theory (Henriquez Rivera, et al., *Phys. Rev. Fluids*, 2016) that captures key effects observed in shear-driven cell-cell collisions and wall-induced hydrodynamic migration. This mechanistic insight paved the way for understanding cell dynamics in sickle cell disease (Zhang et al., *Phys. Rev. Fluids*, 2020).

Mike's contributions in the two additional areas of research – active particle dynamics and turbulent drag reduction – are similarly impactful and impressive. Mike is broadly considered as one of the founders of the field of active particle dynamics, with his seminal contributions including: (1) the first computational study of collective swimming using an accurate microhydrodynamic description of swimmers using a force dipole (Hernandez et al., *Phys. Rev. Lett*., 2005), and (2) the first direct simulations of large populations of hydrodynamically interacting swimmers in a spatially periodic flow domain using efficient computational methods (Underhill et al., *Phys. Rev. Lett*., 2008). In a fourth area, Mike has made key contributions to the field of viscoelastic turbulence. His group discovered the phenomenon of hibernating turbulence, where temporarily suppressed turbulence due to viscoelasticity later emerges after the polymer chains relax, leading to a cycle of low and high degrees of drag reduction (*Phys. Rev. Lett.* 2010). More recently, his group discovered that the recently observed phenomenon of elastoinertial turbulence arises from viscoelastic excitation of the Tollmien-Schlichting waves of classical linear stability theory – these do not play a role in Newtonian turbulence, but in viscoelastic turbulence they emerge as central players (*Phys. Rev. Lett.* 2019).

Mike has authored or co-authored two textbooks that are routinely used in engineering curricula at peer institutions. In his text entitled *Microhydrodynamics, Brownian Motion and Complex Fluids*, Mike provides a clear explanation and coherent treatment of topics that are not readily found in alternative texts including multipole expansions, fundamental solutions to the Stokes equation in confined geometries, coarse-grained models and stochastic differential equations for polymers and suspensions, and applications to linear viscoelasticity and non-linear rheology. A second graduate-level textbook entitled *Applied Mathematics for Chemical and Biological Engineers*, co-authored with Jim Rawlings, provides a comprehensive treatment of mathematical methods in chemical engineering.

On a personal note, I have been inspired by Mike's impressive research since graduate school, when Mike's work on modeling hydrodynamic interactions in long chain polymers directly influenced my efforts in developing Brownian dynamics simulations to complement our single-polymer dynamics experiments on large DNA molecules in extensional flow. As a Ph.D. student, I distinctly recall giving conference presentations at SoR meetings, with Mike sitting in the front row, giving encouraging head nods, and asking supportive and insightful questions. Mike has continued to serve as a supportive mentor for me and several other junior faculty members in the field for many years, and for this, we are eternally grateful.

Mike Graham is a world-leading researcher in rheology and fluid mechanics. His impressive body of work includes several impactful discoveries that have provided the foundation for new lines of inquiry. Given his deeply impactful scientific work – and his selfless and dedicated service to the Society of Rheology – Mike Graham is highly deserving of the Bingham Medal from the Society of Rheology. He truly embodies the highest qualities of scholarship, and we are deeply fortunate to have him as part of our professional community.

The Society of Rheology Mission Statement

Our Vision

An international community of rheologists working towards common goals as articulated in our founding Constitution.

Values

We are the nexus of excellence in the theory and practice of rheology. We are committed to advancement and promotion of the rheological sciences and practice of rheology broadly across diverse groups of individuals, disciplines and industries.

Mission

We aim to expand the knowledge and practice of rheology through education, partnership and collaboration with associated fields, industries, and organizations, as well as to disseminate to diverse communities what rheology is, and how it impacts humanity and the world.

– Adopted by the SoR Executive Committee, 10 June 2017

SoR 95th Annual Meeting
October 13-17, 2024 in Austin, Texas

Technical Co-Chairs: Kendra Erk (*Purdue*) and Safa Jamali (*Northeastern*)
Local Chair: Roger Bonnecaze (*UT Austin*)

Award Lectures:
Michael Graham, *UW-Madison* (Bingham Medal)
Lilian Hsiao, *NCSU* (Metzner Award)


Plenary Lecturers:



"Rheology of Granular Matter on Earth and in the Solar System" by Karen Daniels (*NCSU*) and Doug Jerolmack (*UPenn*)

"The Nexus of Materials, Energy and CO_2 – and the Impacts of Rheology" by Matteo Pasquali (*Rice*)

Educational Short Courses: (1) *LAOS Rheology* (Simon Rogers, *UIUC*)
(2) *Automated Rheology and Applications to Multi-Methods Measurements* (Jeff Richards, *Northwestern* & Thibaut Divoux, *CNRS/ENS de Lyon*)

Of course, the heart of any SoR meeting are the **Technical Presentations** on a wide range of fundamental and applied topics including *additive manufacturing, flow instabilities, sustainability and energy, polymer melts and blends, gels, biology and active systems, colloidal suspensions, advanced measurement tools, construction materials, consumer products, data-driven approaches, interfacial phenomena*, and a special track on *space applications and low-gravity research*.

And as always, there will be **good food & conversations** with your fellow rheologists at Sunday's Welcome Reception and Student Trivia Night, Monday's Downtown Outing, Tuesday's Bingham Medal Reception and Banquet, and Wednesday's Poster Session and Reception.

And don't forget -- abstracts for the Poster Session and Gallery of Rheology are due by August 9th!

Rheology in the Biological Sciences

Alison E. Patteson and Paul A. Janmey

Abstract

Rheology is the science of how materials deform and flow and is a critical aspect of understanding the biomechanical functions of cell and tissue. Historically, scientists have designed simple and cost-effective instruments for assessing the mechanical properties of biological materials to inform their functionality. Cells and tissue are heterogeneous and possess complex mechanical properties. Yet, simple instruments such as falling ball viscometers and torsion pendulums, can often accurately capture and measure different aspects of how biological materials deform that are relevant to physiological conditions. Here we review the application of simple, home-built instruments suitable for probing the viscoelastic properties of biological materials, underscoring the importance of creativity and innovation of experimental tool design in the field of biomechanics.

1. Introduction

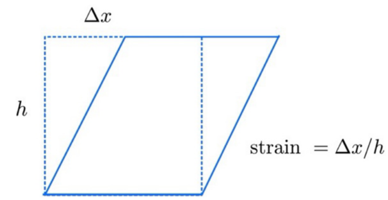
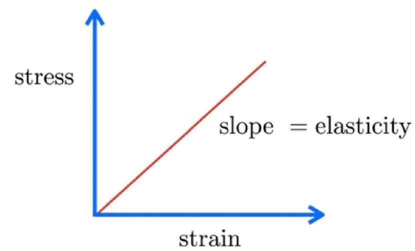
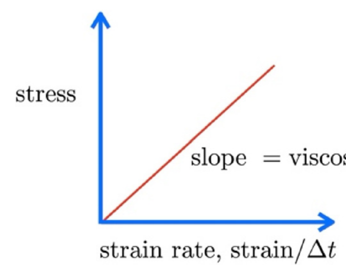
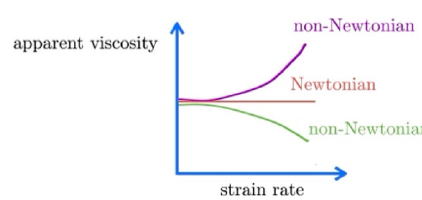
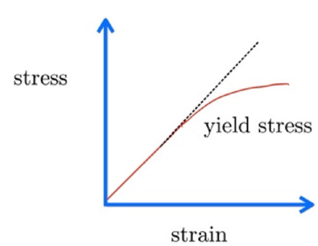
Some form of rheology has been used in biomedical research for centuries, dating back at least to the Greek physicians who diagnosed cancer partly by the appearance of abnormally stiff tissues. The term rheology stems from the Greek 'rheo' meaning to flow. During the Scientific Revolution, Robert Hooke formalized the concept of elasticity in 1678 to link the force applied to an elastic medium and its deformation, and Isaac Newton developed the Law of Viscosity in 1687 to describe the response of an incompressible fluid to shear stress. Most biological materials have complex material properties that are not fully captured by a single elasticity constant or viscosity and can be described as viscoelastic materials that behave in part like solids and in part like fluids in response to external forces (**Table 1**). Some of the first measurements of non-Newtonian viscosity, in which the viscosity is not a constant but depends on shear rate, were done by centrifuging metal particles through the cytoplasm of plant cells, and perhaps the earliest modern day microrheology instrument, consisting of an electromagnet driving a magnetic particle in a soft material visualized on a microscope slide, was used to quantify the viscoelastic properties of the cell interior more than 100 years ago (6). Much of what is known about the rheology of soft tissues, cells, and biopolymer gels was first measured using simple lab-built instruments before the development and widespread accessibility of commercial rotational rheometers in the 1970's (7), which were based on the earlier Weissenberg rheogoniometer (8). As commercial rheometers became more accurate and more sophisticated, enabling viscoelastic measurements at extremely small strains and over frequency ranges of many decades, they also became somewhat less accessible to the researchers and laboratories interested in the viscoelastic properties of biological materials, and especially in the changes that occur in these materials when they become diseased or when they are subjected the stresses and deformations that caused damage.

The heterogeneous structure of biological tissues, the large strains that occur during physiologically relevant deformations of soft tissues, and the limited temperature range over which biological materials function renders some of the sophistication of modern rheological instruments less useful for their characterization than they are in the characterization of stiffer, more crystalline, or otherwise more homogeneous and ordered materials that are more commonly studied by rheological instruments. Non-traditional uses of commercial rheometers that perhaps compromise some of the precision of the instruments but allow for multiaxial deformations of soft materials that more closely mimic the physiological context have recently been revied elsewhere (9). In this article, we discuss some of the creative uses of simple built instruments that probe the biologically relevant aspects of biomaterials, with an emphasis on those that can be built with minimal expense (**Fig. 1**). We focus on methods for macroscopic rheology, and a comparison of methods for microrheology of single cells is available elsewhere (10). We also note here that there are challenges associated with experimentally measuring material properties. These challenges have been described elsewhere, and we refer the reader to the review by Ewoldt, Johnston, and Caretta for reference (9).

2. Applications of rheology to biological samples

The cytoplasm of nearly all cells can transform between liquid-like and solid, gel-like phases (11-13), and these mechanical features have been recognized for nearly a century (6), before even the proteins responsible for gelation of the cell were identified. The cytoskeleton gives cells its dynamic architecture and is primarily responsible for the mechanical properties of cells (14) (**Fig. 2**). When proteins such as actin and myosin that form filaments in muscle cells were also found in non-muscle cells (15, 16), and the other cytoskeletal filaments, microtubules, and intermediate filaments, were identified and purified, a large number of studies using methods of soft matter physics began to characterize the conditions under which gelation occurred, and to quantify

TABLE 1. Common material properties and terms to describe biological materials. For full details, we recommend (36).

Mechanical properties and terms	Description	Schematic
Shear strain	Commonly defined as relative displacements between parallel planes of a material	
Shear stress	Force applied over a material area to deform material; Units, Pascals (Pa)	
Elasticity/Young's moduli/ Elastic modulus	In simple Hookean solids, stress is linear with deformation (strain). If deformation is in shear, the relevant quantity is the shear modulus G. If deformation is elongational, the quantity is the Young's modulus E.	
Viscosity	In simple Newtonian fluids, shear stress is linear with the rate of shear deformation. Viscosity is the proportionality constant.	
Viscoelastic material	Material whose shear stress depends on both shear deformation and shear deformation rates. Silly putty is a classic example. At short times, it holds shape like a solid but will flow over long time periods under the force of gravity (image).	
Non-Newtonian Viscosity	Viscosity that is not constant, but varies with shear-rate.	
Yield Stress	Stress at which a material deforms plastically, which means material cannot return to its original state when stress is removed	

the mechanical strength of the materials formed by cytoskeletal polymers. Nearly all of the fundamental aspects of gelation by cytoskeletal polymers were first discovered using simple equipment, such as falling ball viscometers, torsion pendula, hydrostatic pressure devices, or gravity-based indentation devices. Only later were commercial rheometers used

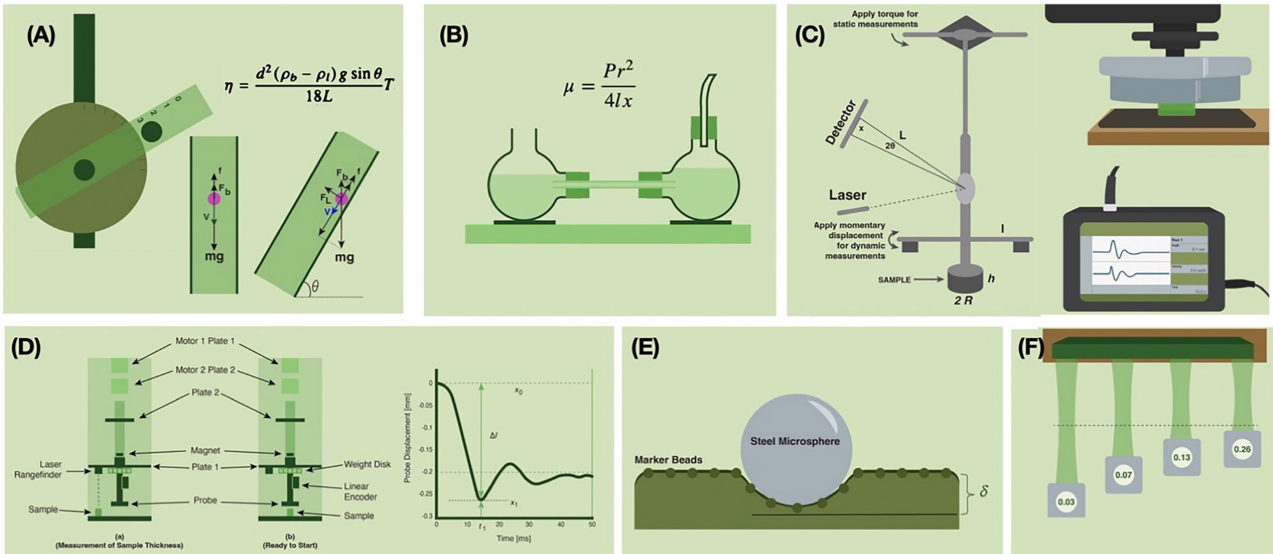


FIGURE 1. Basic instruments for quantifying the mechanical properties of biological materials. The designs include: (A) Falling ball viscometer; (B) Pressure-controlled devices; (C) Torsion rheometers; (D) Uniaxial-impact torsion devices; (E) Surface indentation by gravity of a sphere on a soft surface; and (F) Uniaxial stretching of gels with different amounts of crosslinker.

to study actin- microtubule- and intermediate filament- networks. Today, there are multiple non-invasive diagnostic devices in use to detect stiff tissues as an early reporter of disease, such as the use of ultrasound and magnetic resonance elastography to characterize the development of cancer (17).

3. Falling ball viscometers

Pioneering studies of actin filament rheology were done using newly developed instruments that could measure viscoelasticity of the soft fragile gels they formed (18, 19). One challenge of this method is that it required several milliliters of sample, and other methods were developed to minimize the material

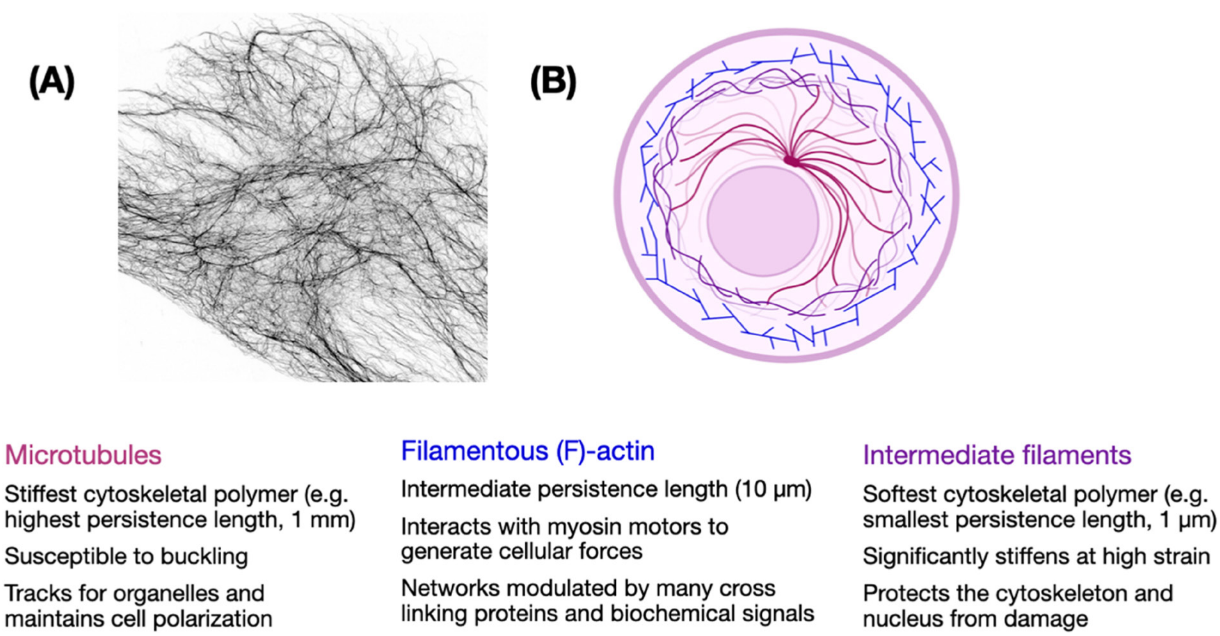


FIGURE 2. The cytoskeleton of the mammalian cell, which strongly impacts the mechanical properties of the cell. The main cytoskeletal polymers are F-actin, microtubules, and intermediate filaments, which each have distinct mechanical properties and persistence lengths that reflect polymer stiffness. (A) Confocal images of mouse embryonic fibroblast, labeled for intermediate filaments. (B) Schematic diagram of cytoskeletal properties and their primary functions. Several crosslinking molecules and molecular motors act to strengthen the cytoskeleton and allow it to generate force. Schematic created with Biorender.

needed. These provided quantitative assessments of viscosity, as well as the yield stress of biopolymer solutions and gels. The most employed method involves falling ball viscometry, in which a dense metal particle is placed on top of a sample held within a thin capillary tube and then released to drop through the sample under the force of gravity (20) (**Figure 1**A). The stress that the particle imposes on the sample is easily calculable from the mass and size of the particle and the gravitational field, and the rate of fluid flow around the particle can be measured based on the time it takes the particle to drop from a given distance. The stress imposed by the bead can be lessened by tilting the sample to acute angles, in which case the ball rolls rather than falls, enabling detection of gels with very small yield stresses. Once the falling ball reaches a steady terminal velocity, which for nearly all applications occurs very soon after its release, the viscosity η is calculated from the expression

$$\eta = \frac{d^2(\rho_b - \rho_l) g \sin\theta}{18L} T$$

where d is the diameter of the ball, ρ_b and ρ_l are the densities of the ball and liquid, respectively, g is the acceleration of gravity, θ is the angle of the capillary with respect to the gravitational field, and T is the time for the ball to drop a distance L.

This method was first developed for simple Newtonian fluids, and its application to non-Newtonian liquids as well as gelling materials is fraught with potential artifacts due to the complicated strain fields around the falling ball and possible interactions with the capillary wall. Nevertheless, the method has been useful for characterizing conditions under which cytoskeletal proteins gel and for identifying factors that alter this gelation. **Figure 3** shows how falling ball viscometry was used to detect the conditions under which neurofilaments form viscoelastic networks and how the combined effects of actin filament severing and cross-linking proteins control the conditions under which actin filaments would form an elastic network. **Figure 3**A shows that the time course of gelation of a neurofilament suspension depends on the ionic conditions of the solvent and the effect of divalent cations that crosslink the filaments. **Figure 3**A also shows that neurofilaments are more efficient in network formation than are the intermediate filaments GFAP, derived from glial cells, rather than neurons. **Figure 3**B shows that a viscous suspension of actin filaments transforms into a gel as it is titrated with increasing amounts of the crosslinking protein filamin C. When the filament length is decreased by addition of the active-filament-severing and crosslinking protein villin, more crosslinker is needed to transform the shorter filaments into a three-dimensional elastic network. These studies and many like them were among the first to show how actin binding proteins and other cytoskeletal factors alter the conditions under which elastic networks formed. These networks could be formed of a single filament type, or in some cases showed that two different cytoskeletal filaments, such as microtubules and neurofilaments, could act together to link each other into a composite network that was not formed by either filament system alone (21, 22).

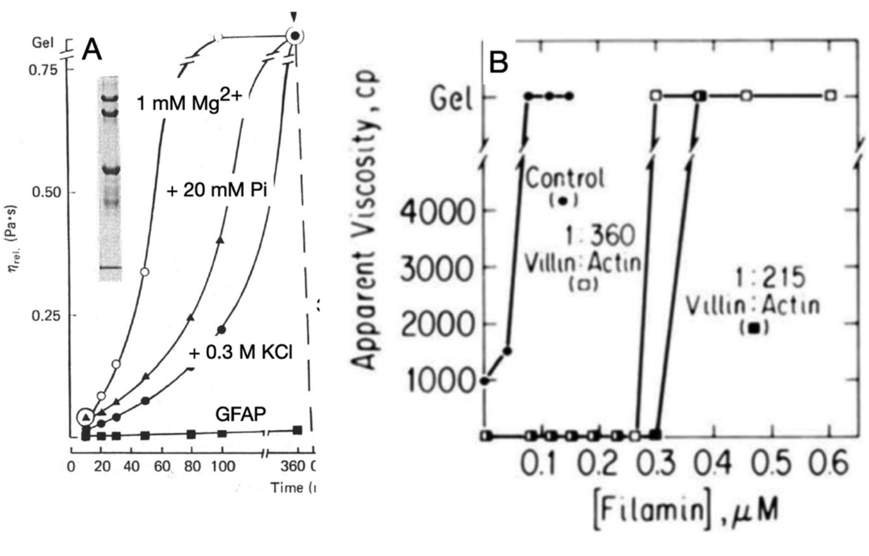


FIGURE 3. Gelation of neurofilaments and actin filaments measured by falling ball viscometry. A: Purified neurofilaments were incubated in solvents containing different ionic conditions, and the resulting increase in viscosity, leading to formation of a gel monitored as a function of time. Glial fibrillary acidic protein (GFAP), in contrast to neurofilaments, did not gel under these conditions. B: Actin filaments are incubated with the cross linking protein filamin C and the actin filament severing protein villin at different molar ratios. Decreasing the actin filament length by villin increased the amount of cross linking protein required to form a gel. Reproduced with permission from (3, 4).

4. Pressure devices

One of the first studies of elasticity in actin-based crosslinked networks used purified actin and actin crosslinking proteins to create either viscous liquids or elastic gels, with a finite yield stress. These studies used a device developed in the 1920s (23) (**Figure 1**B) in which a sample is placed within a capillary connected between a chamber that can be pressurized by pushing a piston into liquid in contact with the gel and a chamber in equilibrium with the atmospheric. The yield stress of the gel is detected by monitoring displacements of particles within it and relating it to the hydrostatic pressure imposed (24). The modulus of rigidity μ at which the gel yields is given by the expression $\mu = Pr^2/4lx$ where P is the pressure at when the gel yields, r and l are the radius and length of the capillary, and x is the distance that a fiducial marker within the gel moves just at the yield point.

These measurements allow an accurate estimate of the yield stress of the network, but do not reliably measure its elastic modulus, since the determination of x is likely to be variable between different samples. However, the device is highly sensitive to proteins that introduce crosslinks between actin filaments and to changes in solution conditions that alter actin gelation. One early study showed that a non-muscle actin crosslinking protein, now called filamin A, was more efficient in forming actin gels than a similar protein purified from muscle, now called filamin C, which was in turn more efficient than gelation by the motor protein myosin (24).

5. Torsion pendulums

While falling ball viscometers can measure the yield stress of gels, the elastic moduli of materials are more easily measured by torsion pendulums (**Fig. 1**C). By changing the moment of inertia of the pendulum arm, it is possible to vary the frequency of measurements over approximately two orders of magnitude. This capacity is illustrated in a study of gelatin gels made in solvents with different amounts of glycerol to vary the solvent viscosity and study the ratio of shear storage and loss moduli and gelatin gels as a function of frequency. The practical range of frequencies in the pendulum used in this study was from 1 to 100 radians/s allowing confirmation that the time temperature superposition principle applied also to these biopolymer materials (25).

The design of the torsion pendulum enables both static stresses and an oscillatory strain to be imposed simultaneously. By twisting a calibrated wire that suspends a pendulum a known amount, a constant shear stress can be applied to the sample and the strain resulting from that stress defines a static shear modulus. In addition, a small oscillatory strain can be imposed by deflection of the pendulum arm allowing a low amplitude dynamic measurement to be superimposed on a static stress. In this way the so-called differential shear modulus, a low strain modulus measured on the sample held at a variable and possibly large shear strain could be measured. For well cross-linked samples with minimal shear creep, it is possible to adjust the static stress to impose a specific static strain on top of which the low strain oscillatory measurement could be made.

This capacity is illustrated in early studies of biopolymer networks. Figure 4A shows a typical damped oscillatory displacement caused by a momentary impulse to the pendulum arm that induces free oscillation at a frequency that depends on the moment of inertia of the pendulum, the size of the sample, and its viscoelastic parameters. The shear storage (G') and loss (G'') moduli at a radial frequency w are calculated from the expressions:

$$G'(\omega) = w^2 I/b\ (1 + D^2/4\pi^2) \text{ and}$$
$$G''(\omega) = w^2 I/b\ (D/\pi)$$

where I is the moment of inertia, $b = \pi R^2/2h$ is the form factor of the disc-shaped sample with radius R and height h, and D is the logarithmic decrement in oscillation amplitudes $= ln\ (A_n/A_{n+1})$ where A is the amplitude of the nth oscillation.

The impulse to the pendulum arm can be imposed either while the sample is at rest or subjected to a static torsion caused by twisting the wire. **Figure 4**B shows how the shear storage modulus of a macrophage extract gel, composed mainly of actin filaments and their cross linking proteins, depends on the magnitude of the shear strain. The macrophage gel strongly stiffens as the shear strain increases up to approximately 5%, but then the gel ruptures abruptly at strains above 7%. Such a gel might be difficult to measure by conventional stress controlled rheometers, which without prior knowledge of the elastic modulus expected, initially impose an arbitrary stress to reach a target maximal strain, but that might overshoot the strain, and thereby rupture the network before measurement.

In **Figure 5**A a crosslinked fibrin gel is deformed to variable shear strains and then the differential shear modulus is measured, illustrating the strong shear strain stiffening effect of fibrin. The pendulum allows the constant strain to be reversed, to measure possible hysteresis in the sample. For samples that exhibit a finite shear creep within the time needed to do the oscillatory measurement, which is typically a few seconds, a constant strain cannot be imposed by the pendulum, but a constant stress can be imposed, on top of which the differential shear modulus is measured. This capability is shown in a study of neurofilament networks (Fig 5B) which unlike fibrin gels are non-covalently cross-linked rather than covalently bonded and illustrates the even more striking sheer strain dependence of the shear modulus of neurofilament networks, and their ability to resist large stresses. Measurements of differential shear modulus at constant stresses are advantageous because the oscillatory measurements are within their linear range, but imposed on a highly deformed sample, and provide data that are more compatible with theoretical modeling (26).

A functional torsion-rheometer can be built at home for a minimal cost. The first torsion-rheometers were designed with a plate hanging from a wire, which offered minimal friction when applying torque to a sample (see **Fig. 1**C). The oscillations

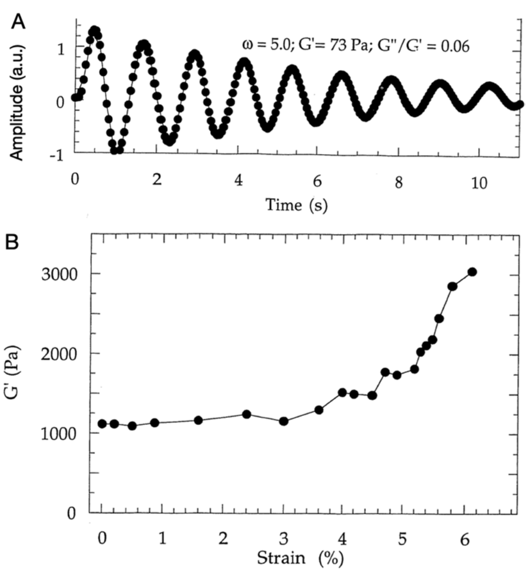


FIGURE 4. Measurements of viscoelasticity using a torsion pendulum. A: The free damped oscillation of a polymerized actin sample after a momentary imposition of < 2 % strain. The storage modulus is calculated from the frequency and the loss modulus by the decay of successive peak amplitudes. B: The shear storage modulus of a macrophage extract at increasing levels of static strain above which a small oscillatory strain is imposed. Reproduced with permission from (5).

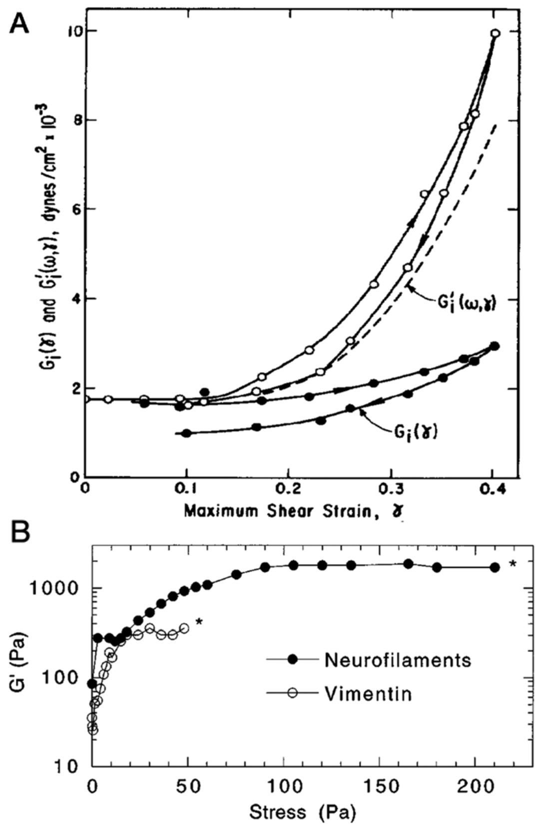


FIGURE 5. Differential shear moduli of fibrin and neurofilament gels at increasing shear strain amplitudes. A: A covalently cross-linked fibrin gel was deformed by static torsion in a pendulum to a constant strain, and a small oscillatory deformation was superimposed by a small impulse on the pendulum arm. B: Differential shear modulus of non-covalently cross-linked neurofilament gels at increasing levels of sheer stress. Reproduced with permission from (1, 2)

of the plate can be measured precisely using a mirror, laser, and a photodetector. An alternative design was recently described, which required fewer experimental components. Namely, this 'pocket rheometer' requires essentially only an angular sensor to be coupled to the plate that applies torsion to the sample (27). The accuracy of this design depends on the accuracy of the sensor and friction between the plate and the sensor, but a range of different frequencies and strain amplitudes can be applied to measure the elastic and loss moduli of different gels (such as agar and phantom tissue constructs) with minimal equipment.

6. Uniaxial-impact torsion devices

The same ideas on which the torsion pendulum is based can also be used to construct an instrument to measure the dynamic viscoelastic repose after a pulse of uniaxial deformation (28). **Figure 1**D shows a device in which a weight is rapidly dropped onto the surface of a soft material, in this example the flesh of an apple. The apparent Young's modulus and viscous loss are calculated from the known mass of the probe, the amplitude of indentation, and decay of the displacement amplitude. The electronics of this device allows very rapid detection of motion, allowing measurement of relatively stiff samples (>MPa).

7. Surface indentation by spheres

A versatile and perhaps even simpler method to measure the elastic modulus of the surface of soft biomaterials involves placing a dense metal sphere with radii in the range of a millimeter onto the surface of a flat sample and then measuring the indentation of the surface by conventional microscopy (**Figure 1**E). The density difference between the metal probe and the biological sample, which typically has a density very close to that of water, imposes a stress due to the force of gravity on the bead that can range from *O*(10) μN to *O*(100) μN depending on the radius of the bead and the density of material from which it is made. The diameters of easily available commercial spheres range from 400 μm to 1 mm (29). The resulting surface stresses imposed by these spherical indenters are conveniently in a range that can put significant deformation but generally not break hydrogels of biological tissues which have Young's moduli in the range of *O*(10) - *O*(100) Pa. Some advantages of this method are the lack of need to calibrate force sensors, since the stress is accurately defined by the size and density of the particle, and the resulting strain can be accurately measured by conventional fluorescence microscopy because the typical displacement underneath the millimeter sized bead is in the range of a few 100 microns and easily be measured accurately by refocusing on the maximally displaced markers (30-32). Multiple millimeter or sub millimeter beads can be placed on a single sample, and simultaneously the local stiffness can be measured over a wide area.

In the simplest case, the Young's modulus of the sample *E* is calculated from the expression

$$E = \frac{3\left(1 - \nu^2\right)F}{4R^{0.5}\delta^{1.5}}$$

where ν is the Poisson's ratio of the sample (commonly near 0.5 for incompressible tissues, but often variable for hydrogels) F is the force applied by a bead of radius R and δ is the distance of maximal indentation.

Some disadvantages of the method are that calculation of an apparent Young's modulus from the displacement requires the use of a Hertz relation for which surface adhesive forces and Poisson ratios need to be measured or assumed (33) and the thickness of the sample needs to be accounted for in the calculation of elastic modulus (32). However similar issues apply to any measurement of surface elasticity using an atomic force microscope or other indenting probe, and the formalisms for interpreting force indentation curves by these methods are very well developed. An excellent summary of the use of bead indentation for biomaterial rheology is available (31).

8. Uniaxial stretching

Perhaps the simplest measure of elastic modulus, suitable for structures such as tissues or stiff hydrogels that can be gripped at both ends, is to measure their elongation when forces are applied by hanging weights at one end. This method is analogous to laboratory demonstrations illustrating Hooke's law, in which increasing masses lead to increasing elongation of a spring from which a spring constant can be derived. The utility of this simple method is demonstrated by its use to measure the Young's modulus of polyacrylamide gel substrates (**Figure 1**F) in the landmark study that demonstrated how important substrate stiffness is to cell morphology and motility (34).

9. Conclusions and Perspectives

In this article, we have described many different types of creative and home-built designs to measure mechanical properties of biological materials. We covered simple early devices, such as falling ball viscometers and torsion pendulums that have helped us better understand the viscoelastic behavior of soft tissues, cells, and biopolymer gels. Even though commercial rheometers are more sophisticated and advanced, the complexity and heterogeneity of biological materials often require more adaptable and accessible methods. We are inspired by the do-it-yourself (DIY) culture and the possibility of new creative designs. DIY-design, brought to the attention of public in particular during the shelter-in-place orders of COVID-19 have generated new techniques, as recently described by Hossain and Ewoldt (35). These methods not only offer a practical alternative for researchers with limited resources but also encourage creativity and innovation in experimental design.

Authors

Paul Janmey is Professor of Physiology at University of Pennsylvania. Paul received is A.B. in Chemistry and Philosophy at Oberlin College in 1976 and received a Ph.D. in Physical Chemistry at University of Wisconsin, 1982. His lab studies several aspects of cell mechanics, including how cells sense and respond to the stiffness of soft materials (usually hydrogels linked with cell adhesion proteins), mechanical properties of cytoskeletal polymers, and how cell membrane structure mediated by inositol phospholipids lead to production of signals that remodel the cytoskeleton.

Alison E. Patteson is an Associate Professor of Physics at Syracuse University. Her research focuses on the soft matter physics of cell motility and biofilm development. Alison is a native of Lancaster County, PA and received her B.S. in Physics and Mathematics from Kutztown University in 2011. Her Ph.D. was in Mechanical Engineering at the University of Pennsylvania (UPenn), studying active complex fluids and bacteria motility with Prof. Paulo Arratia from 2011-2016. Her postdoctoral research was with Prof. Paul Janmey at UPenn on the vimentin cytoskeleton and confined cell motility (2016-2019). Alison took a faculty position in 2019 at Syracuse University. She is a recipient of the APS Dissertation Award in Statistical and Non-linear Physics (2018), NIH Outstanding Investigator Award (2021), and APS Maria Goeppert Mayer Award (2024). Alison is also a Cottrell Scholar (2023) and Sloan Research Fellow (2023). She loves mechanobiology, working with students, and college basketball.

Acknowledgements

Cell image courtesy of Maxx Swoger and the Blatt BioImaging Center at Syracuse University. AP acknowledges support from NSF MCB 2026747, NSF CMMI 2238600, and CS-CSA-2023-097 from the RCSA.

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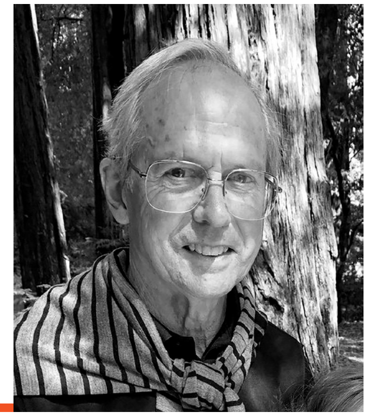
In Memoriam: William Bailey Russel (1945 – 2023)



By William R. Schowalter

William Bailey Russel, the Arthur W. Marks '19 Professor of Chemical and Biological Engineering, Emeritus, and Dean of the Graduate School, Emeritus, passed away in Princeton on September 24, 2023, at the age of 77. An internationally renowned scholar and a tireless and selfless institutional, academic and professional leader, he spent his entire career at Princeton University. He leaves an extraordinary legacy through his research, and he did much to establish colloid science as a vital branch of modern engineering.

Bill was born on November 17, 1945, in Corpus Christi, TX and grew up in Fort Worth, TX. He received his undergraduate degree in Chemical Engineering from Rice University in 1969, and his Ph.D., also in Chemical Engineering, from Stanford University, in 1973. Following a NATO post-doctoral fellowship at Cambridge University, he joined Princeton's Chemical Engineering Department in 1974. Bill served as Chair of the Chemical Engineering Department between 1987 and 1996 and was Director of the Princeton Materials Institute between 1996 and 1998. He served as Dean of Princeton's Graduate School for twelve years and retired from the University in 2017.

Bill's research centered on the science and engineering of colloidal dispersions. His interest was in advancing our fundamental knowledge of the physics and chemistry of these dispersions, meaning that rheology was a key component of his work but not the foundation of it. Indeed, it was two decades after his PhD before he began publishing regularly in journals that contained the word "Rheology" in the title. In 1983, his work with Alice Gast and Carol Hall on polymer-induced phase separations appeared in the *Journal of Colloid and Interface Science* (*JCIS*), and those results established his reputation as an authority on the rapidly evolving subject of modern colloid science. The authors proposed a statistical mechanical theory of polymer-induced phase transitions in colloidal suspensions. Their work is now a classic and has become the basis for the rational engineering design of polymer-stabilized colloidal suspensions. With Princeton colleague Paul Chaikin, Bill performed definitive experiments in normal gravity and microgravity, on the order-disorder transition in hard-sphere colloids. This body of work is remarkable for its imaginative use of electrical fields and gravity to control the structure, growth kinetics, and density of colloidal crystals. Important results include the determination of the equation of state of hard spheres across the fluid-crystal transition, the detailed measurement of nucleation and growth rates, and the determination of elastic constants for hard-sphere crystals.

Bill and his students pioneered the application of nonequilibrium statistical mechanics and rheo-optical and scattering techniques to elucidate the relationship between structure and rheology in concentrated colloidal dispersions. This work yielded deep insights into the rheology of charged dispersions and dispersions containing dissolved, grafted, associative, and hydrophobically modified polymers. Another area in which Bill's group made major contributions is the rheology and consolidation of colloidal gels, in which the dispersion medium is a solid. This vast body of work encompasses elegant mathematical models of ultrafiltration, mass transfer in drying fronts, and fracture mechanics, as well as experimental measurements of latex film deformation. Bill supervised 40 Ph.D. theses, and many of his former students have risen to prominent positions in academia and industry.

Although his findings had rheological consequences, his papers would tend to be in journals such as *JCIS*, *Macromolecules*, *JChemPhys, etc*., and would be classified as polymer science or colloid science. Nevertheless, his rise to become an authority on rheology is evident from the appearance of a single-author review in the *Journal of Rheology* (*JOR*) in 1980 on the role of colloidal forces in the rheology of suspensions, even though his first refereed paper in *JOR* did not appear until 1987.

Evidence that this breadth of research accomplishment also exhibited unusual depth is shown in the variety of organizations from which he received high honors. These include the American Institute of Chemical Engineers' Walker (1992) and Alpha Chi Sigma (2010) Awards, the Society of Rheology's Bingham Medal (1999), and the American Chemical Society's Colloid and Surface Chemistry Award (2007). He was elected to the National Academy of Engineering (1992) and the American Academy of Arts and Sciences (1995).

Between 1993 and 2005, Bill was actively engaged in the Society's leadership, serving as president between 2001 and 2003. During this period, he was similarly engaged in key committee positions in AIChE and NAE and, of course, at Princeton University. His advice as an editorial board member was sought and received by numerous prestigious research journals.

It was noted above that Bill served as Dean of the Graduate School at Princeton University for 12 years. The Graduate

School at Princeton bears, in many ways, a closer resemblance to the traditions of Oxford and Cambridge than to typical graduate schools in this country. There are separate living and dining facilities for graduate students, the dean has spacious living quarters close to those of graduate students, and the dean has typically been chosen on the basis of high scholarly attainment and special administrative abilities. Bill provided both.

Because *Colloidal Dispersions* had an important effect on the advancement of the subject and because I could personally observe the genesis of the book, I close with a brief description of how the concept of a book evolved and how Bill led in translating the concept into a successful product.

Colleague Dudley Saville, Bill, and I had complementary research interests, and we began in the mid-1970s to have regular research meetings attended by the three of us and our graduate students. The students were full participants in the presentations and the discussions, meaning these were meetings, not seminars. When the meetings began, the three of us did not have a book in mind. That idea probably arose when we were preparing to teach together a graduate course on colloids and were reminded of the number of unanswered questions that had emerged during our research meetings. Note, however, that conversion of a book idea into a physical object took a decade. (Potential book writers, take note.) It was certainly Bill who was the primary instigator and driver of the project, and it was around 1980 that the three of us began meeting to consider a prospectus and to begin writing content. Without Bill, the book would never have appeared. He was the intellectual leader for it as well as the point person who found a publisher and worked with Cambridge University Press to handle the uncountable details that are inevitable. Without Bill's persistence and patience we would not have reached the finish line.

Bill's fundamental research, his impeccable integrity, and his selfless dedication to people and to his science set a gold standard for anyone fortunate enough to interact with him. His passion was in the quality of the work he did. In the words of his colleague, Professor Sankaran Sundaresan, "In Hindu culture, we are told to aspire to be *karma yogis*, which means that your focus should be on the tasks you are doing for the good of the people around you, not their fruits and certainly not the rewards they bring you. Bill exemplified the philosophy of *karma yoga*."

William R. Schowalter

Note: Portions of this article contain material adapted from a Memorial Resolution passed by the Princeton University Faculty on February 5, 2024, and composed by Professors Pablo Debenedetti, Rodney Priestley, Sankaran Sundaresan, and William Schowalter.

Secretary's Report

By Kalman Migler

The Secretary's report now consists of the motions adopted in the prior year by the Executive Committee and by the full Society, excluding pro forma motions. The full minutes are available upon request from: secretary@rheology.org

Fall 2023 Executive Committee Meeting

- Anti-harassment policy approved. Policy available on SoR Website
- Approved the move of $100k of SoR assets into a 5-year bond ladder, in support of SoR investment policy.
- Approved new Bingham Medal nomination guidelines. No more than 3 supporting letters that address the nominee's contributions. New guidelines on Bingham Medal webpage.
- Approved new Metzner Award nomination guidelines. Must include a brief summary of participation in Society activities. Reduce by one, the number of letter writers for Metzner. If substantially equal nominees, prioritize the person with fewer remaining years of eligibility. New guidelines on Metzner award webpage.
- Approved new Fellow nomination guidelines: up to 50-word citation to be included. Require a two-page summary of contributions to rheology and service to society. New guidelines on Fellows webpage.

Fall 2023 Annual Business Meeting

- Motion to approve budget passes. See Treasurer's report.
- Approved motion to submit proposed constitutional and rules changes to the full membership. Proposed changes are available on SoR website.
- November 2023 - membership wide vote on constitutional and rules changes passes. Updated constitution available on SoR website.

Spring 2024 Executive Committee Meeting

- Approved a total budget of $70k for RRS including both RRS and student travel grant.
- Approved Rheology Venture Fund proposal on Space Rheology Initiative for $12k
- Approved Rheology Venture Fund proposal for Rheology Academy- an Online Education Platform for SoR $23k over two year spending period.

Treasurer's Report

By S. Lisa Biswal

The Society of Rheology (SoR) remains financially stable. SoR has significant financial reserves, a strong brand, and a dedicated membership base. This report will detail the major activities of the Society of Rheology and how they are accounted for in the various SoR accounts held at American Institute of Physics (AIP), the American Institute of Physics Publishing (AIPP), the Schwab accounts, and QuickBooks online account. Each section of this report is built around a major activity for the SoR. For the year 2023 the SoR ended with a net revenue of $202,296 (see Summary Table 1). It is important to note that this value includes $49,328 growth in SoR Schwab investments, which is noted as an unrealized change in value. Additionally, the lack of annual meeting expenses contributed to an overall increase in revenue in 2023.

Revenues of Society of Rheology

The realized revenues for SoR are shown in Figure 1. The bulk of SoR revenue continues to be made from the publication of the Journal of Rheology, which has held steady in the past year. The second largest source of revenue is the membership dues, which has remained steady over the past years. Because of favorable interest rates, the interest income earned last year was higher than in previous years. Lastly, some of the sponsorships for the previous annual meetings were received and allocated to 2023 revenue.

Journal of Rheology

Beginning in 2019, the SoR began a publishing partnership with AIPP, resulting in increased revenue through consortium marketing and decreased cost of producing the journal resulting in increased JOR net revenue. The partnership will guarantee revenue of $100k/yr. to the Society of Rheology. Any net revenue greater than the $100k minus the expenses, will be split with AIPP in a 50-50 arrangement. A new 5-year agreement was signed with AIPP to continue this agreement. As shown in Figure 2, the JOR revenue remains steady and is nearly always above the SoR net income, indicating the importance of JOR on supporting SoR activities and operations.

Expenses of the Society of Rheology

The various expenses for SoR are shown since 2015 in Figure 3. In

TABLE 1. Summary of SoR 2023 Net Revenue

Society of Rheology January-December 2023			
Revenue		**Expenses**	
Dues	$ 54,545	AIP Expenses	$ 34,997
Journal of Rheology	$ 259,448	Journal of Rheology	$ 53,986
Pledges	$ 31,000	Awards	$ 28,065
Interest Income	$ 25,728	Student Travel	$ 38,127
		Bulletin	$ 12,770
Unrealized Gain in Investment Value		Business Mtgs	$ 23,211
	$ 49.328	Other	$ 26.596
Total Revenue	**$ 420,048**	**Total Expenses**	**$ 217,752**
Net Revenue	**$ 202,296**		

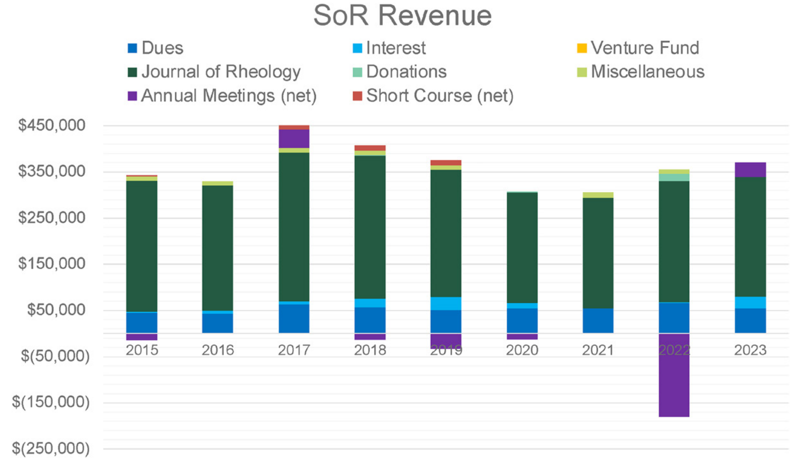


FIGURE 1. Revenue sources for SoR from 2015-2023.

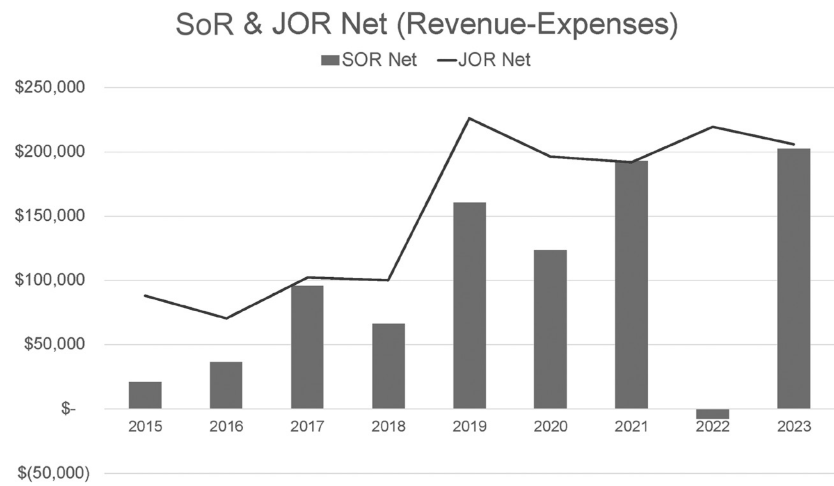


FIGURE 2. The net revenue from the Journal of Rheology and SoR Net Revenue.

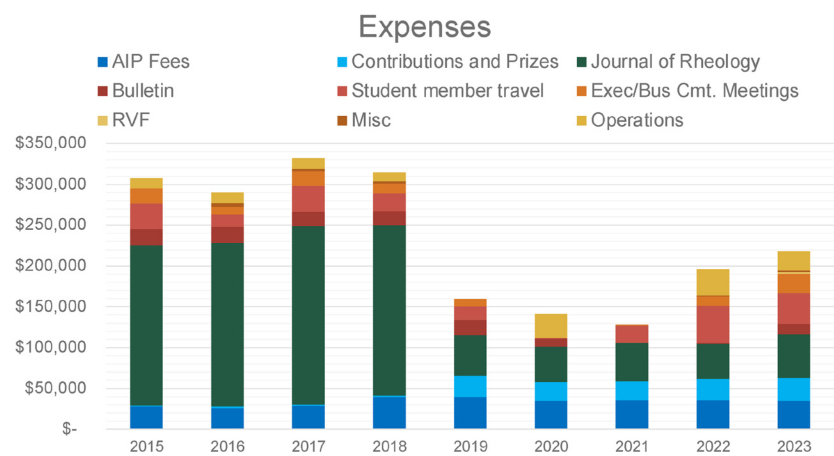


FIGURE 3. Expenses for the Society of Rheology from 2015-2023.

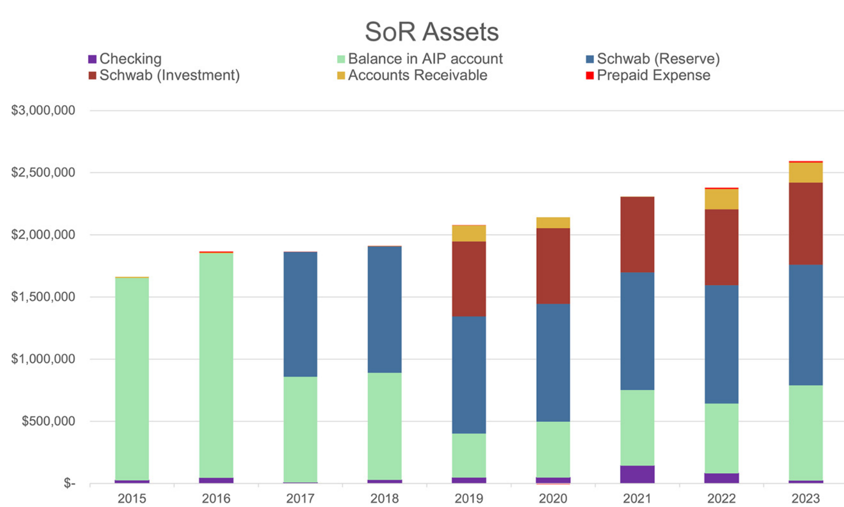


FIGURE 4. Society of Rheology Assets from 2015-2023.

addition to publishing and AIP partnership expenses, other major expenses in 2023 include supporting mission related activities, including awards and student travel grants to attend ICR. This past year also included an ExCom meeting in the Spring and business meeting in the Fall. The Rheology Venture Fund (RVF) is a new initiative supported by AIP to support rheological outreach activities. The misc. expenses cover international activities and the history project. Operations covers professional services such as contracted accountants, webservices, legal fees, and insurance.

Assets of the Society of Rheology

A summary of SoR assets since 2015 is shown in Figure 4. This past year, SoR assets have grown to be above $2.5 million. The balance in the AIP account is from collection of membership dues and JOR revenues. The Schwab reserve account is designed to support emergency expenses. The funds in this account are primarily placed in low risk, fixed income assets, such as US treasury notes and short-term bonds. The interest income reported under revenue is primarily from this account. The Schwab investment account was set up in 2018 for SoR to make equity investments with the goal to generate another revenue source to support the SoR mission and goals. A total of $225,000 was invested into an Index Fund that is responsible for unrealized growth of $49,328 this past year. The rest of the funds are in CDs with 5% yield rates. Accounts receivable and prepaid expenses are assets committed to future activities.

A balance sheet summarizing the total liabilities and net assets is shown in Table 2.

Budget for 2024

At the business meeting this past October, the membership voted to adopt the 2024 budget, shown in Table 3. Compared to the actual expenses from previous years, we expect that the annual meeting in Austin will operate at a loss due to increased food costs. We also added budgets to support the Rheology Research Symposium (RRS) and the Rheology Venture Fund (RVF). Previously the RRS expenses were included directly into the annual meeting expenses. Based on anticipated

TABLE 2. Balance Sheet for SoR from 2019-2023

The Society of Rheology, Inc. Balance Sheet as of Dec 31, xxxx	**2023**	**2022**	**2021**	**2020**	**2019**
Assets					
Cash in checking acccunt(s)	$ 21,963	$ 80,871	$ 142,871	$ 47,741	$ 46,727
Balance in AIP acccunt	$ 767,319	$ 562,945	$ 608,866	$ 449,440	$ 354,665
Schwab (Reserve)	$ 971,353	$ 950,550	$ 945,384	$ 947,471	$ 942,513
Schwab (Investment)	$ 661,111	$ 612,221	$ 608,866	$ 608,604	$ 602,731
Acccunts Receivable	$ 160,341	$ 161,638	$ 1654	$ 88,151	$ 129,885
Prepaid Expense	$ 11,765	$ 11,000	$ (8.500)	$ 36	
Total Assets	**$ 2,593,852**	**$ 2,379,225**	**$ 2,307,641**	**$ 2,132,907**	**$ 2,076,557**
Liabilities and Net Assets					
Liabilities					
Deferred revenue	$ 146,993	$ 29,374	$ 13,166	$ 32,245	$ 126,398
Venture Capital Fund	$ 26,455	$ 26,455	$ 26,900	$ 27,000	
Total Liablities	$ 173,448	$ 55,829	$ 40,066	$ 59,245	$ 126,398
Net Assets					
Publication reserve	$ 450,000	$ 450,000	$ 450,000	$ 450,000	$ 450,000
Student travel grant reserve	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000
Annual Meeting reserve	$ 300,000	$ 300,000	$ 300,000	$ 300,000	$ 300,000
Operating reserve	$ 150,000	$ 150,000	$ 150,000	$ 150,000	$ 150,000
Unrestricted	$ 1,288,107	$ 1,774,048	$ 1,144,780	$ 1,020,159	$ 859,439
Net Revenue	$ 202,296	$ (7,671)	$ 192,795	$ 123,503	$ 160,720
Total Net Assets	$ 2,420.404	$2,323.395	$2,267,575	$ 2,073,662	$ 1,950,159
Total liabilities and net assets	**$2,593,852**	**$2,379,225**	**$ 2,307,641**	**$ 2,132,907**	**$ 2,076,557**

increased costs associated with RRS, the ExCom voted to increase the RRS budget to $50K at the Spring ExCom meeting. It is important to note that although 2024 has a net negative budget, it is expected that unrealized gains by the increased value associated with the investment account will offset that loss.

(Table 3 continues in the next page)

The Society greatly appreciates the contributions from the three members of the Audit Committee: Anthony Kotula (Chair), Brian Edwards and Jeffrey Martin. The members of the Audit Committee meet regularly to examine the accounts in Quickbooks and report their findings to the Executive Committee.

The Society also appreciates the contributions from the three members of the Financial Advisement Committee: Rekha Rao (Chair), Phil Sullivan, and Jonathan Seppala. The Financial Advisement Committee reviews investment strategies to provide investment choices aligned with SoR's mission and risk tolerance.

TABLE 3. Detailed list of receipts and expenses from 2019-2023. The 2024 Budget voted at the Oct 2023 business meeting shows new budgets for the Rheology Research Symposium (RRS) and Rheology Venture Fund (RVF).

The Society of Rheology Receipts and Disbursements	**2024 Budget**	**2023**	**2022**	**2021**	**2020**	**2019**
RECEIPTS						
Dues	$ 60,000	$ 54,545	$ 66,590	$ 55,166	$ 55,154	$ 50,890
Interest	$ 40,000	$ 25,728	$ 2,250	$ 101	$ 11,688	$ 28,493
Venture fund(asset)	$ -	$ -	$ -			
Journal of Rheology	$ 250,000	$ 259,448	$ 261,986	$ 239,631	$ 239,813	$ 275,613
Donations	$ -		$ 15,000		$ 1.51	
Miscellaneous	$ -	$ -	$ 10,423	$ 11,548		$ 10,000
Annual Meetings (net)	$ (100,000)	$ 31,000	$ (179,684)		$ (12,566)	$ (33,001)
Short Course (net)	$ -	$ -	$ -	$ -	$ -	$ 10,371
TOTAL RECEIPTS	**$ 250,000**	**$ 370,720**	**$ 176,565**	**$ 306,446**	**$ 294,090**	**$ 342,366**
DISBURSEMENTS						
AIP Dues Bill & Collect.	$ 36,000	$ 34,997	$ 35,969	$ 35,417	$ 34,940	$ 39,769
Contributions and Prizes	$ 28,000	$ 28,065	$ 25,987	$ 23,062	$ 22,742	$ 25,996
Journal of Rheology	$ 50,000	$ 53,426	$ 42,492	$ 47,563	$ 43,407	$ 49,308
Bulletin	$ 10,000	$ 12,770	$ 1,371		$ 9,799.70	$ 18,920
Exec/Bus Cmt. Meetings	$ 10,000	$ 23,211	$ 10,971	$ 1,605	$ -	$ 9,318
Pres. Discretionary Fund	$ 5,000	$ 3,339	$ 4,718	$ -	$ -	$ -
Treas. Discr. Fund	$ 3,000	$ -	$ 1,637	$ -	$ 755	$ -
Bulletin Editor support	$ 4,000	$ -	$ -	$ -	$ -	$ -
Progr. Chm. Discr. Fund	$ 5,000	$ -	$ -	$ -	$ -	$ -
Webmaster Discr. Fund	$ 5,000	$ 5,188	$ 313	$ -	$ 2,702	$ -
International Activities Fund	$ 3,000	$ 1,939	$ -	$ -	$ -	$ -
Liability Insurance	$ 8,000	$ 1,930	$ 11,862	$ -	$ 7,189	$ -
Accountant	$ 5,000	$ 6,428	$ 5,462	$ -	$ -	$ -
History Project	$ 3,000	$ -	$ 1,092	$ -	$ -	$ -
Legal Fees	$ 5,000	$ 5,407	$ 8,210	$ -	$ 17,581	$ -
Student member travel	$ 25,000	$ 38,127	$ 45,567	$ 20,532	$ 1,000	$ 16,200
RRS	$ 50,000	$ -	$ -	$ -	$ -	$ -
RVF	$ 30,000	$ 2,021	$ -	$ -	$ -	$ -
DEI	$ -	$ -	$ -	$ -	$ -	$ -
Annual meetings, future	$ 5,000	$ -		$ -	$ -	$ -
Website	$ 2,500	$ 906	$ -	$ -	$ 566	$ -
Targeted Investments	$ -	$ -	$ -	$ -	$ -	$ -
Miscellaneous	$ -	$ -	$ 50	$ -	$ 29,906	$ 22,135
TOTAL DISBURSEMENTS	**$ 292,500**	**$ 217,752**	**$ 195,700**	**$ 128,179**	**$ 170,587**	**$ 181,646**
OTHER RECEIPTS						
Unrealized Change in Account Value		$ 49,328	$ 11,464			
SOR Net	**$ (42,500)**	**$ 202,296**	**$ (7,671)**	**$ 192,795**	**$ 123,503**	**$ 160,720**

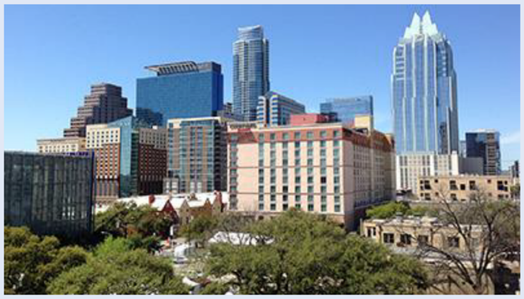
Saga of a crumpled piece of paper

I was a crumpled piece of paper
till your curiosity unfurled me.
An excited child in you ironed away
my wrinkled and discarded past
and laughed at what I bore boldly
written in *her* hand, in pencil
in dark arches, colons, commas,
with a full stop.

You laughed till your tears
made maps over me
and then you smiled and erased away
her words, *her* punctuation,
and took crayons to wax me with color.
Fascinated by the impact of your hands,
you embellished me,
revived me and then artfully
sold me away

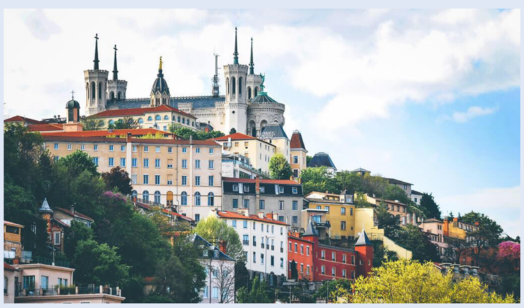
Appears in Vivek Sharma's first book of poems *Saga of a Crumpled Piece of Paper* (63 Poems, English; Writers Workshop, Calcutta, 2009).

Future Meetings & Workshops



95th SoR Annual Meeting
October 2024
Austin, Texas

CompFlu-2024
16 - 18 December 2024
IIT Hyderabad, India



Annual European Rheology Conference (AERC)
April 14-17, 2025
Lyon, France

9th Asia-Pacific Rim Conference on Rheology
July 20-25, 2025
Kobe, Japan

96th SoR Annual Meeting
October 19-23, 2025
Santa Fe, New Mexico

97th SoR Annual Meeting
October 25-29, 2026
Boston, Massachusetts

Anton Paar

Modular, easy-to-use

Rheometer-Raman Combination

MCR Series, Cora 5001

Simultaneous measurement of physical and chemical properties

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