Sol Michael Gruner

The John L. Wetherill Profess of Physics, Cornell University

Background:

Massachusetts Institute of Technology	S.B.	1972	Physics
Princeton University	Ph.D.	1977	Physics
Princeton University, Assistant Professor			1978-1985
Princeton University, Associate Professor			1985-1991
Exxon Research, Research & Engineering, Visiting Fellow			1986
Institute for Theoretical Physics, University of California at Santa Barbara, Visiting Appointment			Fall 1989, Fall 1994
Princeton University, Professor			1991-1997
Robert Wood Johnson Medical School, Dept. of Pathology, Visiting Appointment			1994-1995
Cornell University, Professor, Dept. of Physics			1997-2013
Director, Cornell High Energy Synchrotron Source (CHESS)			1997-2013
Assoc. Direc., Cornell Lab for Accelerator-based ScienceS and Education (CLASSE)			2011-2013

Honors and Activities:

Phi Beta Kappa; Sigma Xi	
Danforth Foundation Fellowship	1972-1976
Fellow, American Physical Society	1990
Fellow, American Association for the Advancement of Science	2001
Member, American Academy of Arts & Sciences	2011
Founding Member, Collaborator, and Technical Advisor, ECR/PRT on X-9, NSLS	1979
Chairman, NSLS Users Subgroup on Time-Resolved Diffraction	1982
Scientific Advisory Board, The Liposome Co.	1983
Co-Chairman of 2nd and 3rd Biannual Princeton-Liposome Research Conference on Lipid Membranes	1985 and 1987
Editorial Board, Journal of Liposome Research	1988; 1998-2005
Scientific Advisory Board, Enzymatics Co.	1988-1990
Editorial Board, *Review of Scientific Instruments*	1990-1992
Member at Large, Div. Biol. Physics, Amer. Phys. Soc.	1990
Organizer and Executive Board Member of Princeton Materials Institute	1990
Dept. of Energy Health & Environ. Res. Advisory Subcommittee, Structural Biology	1992
Publications Committee, *Biophysical Journal*	1993-1994
Editorial Board, *Internat. Series in Basic and Appl. Biol. Physics* (AIP Press)	1994-1996
Program Committee, Synchrotron Radiation Instr. '95 conference	1995
NIH BioCARS Advisory Committee (APS Synchrotron)	1994
CMC-CAT Executive Committee (APS Synchrotron)	1995-1997
Assoc. Faculty, Princeton Environmental Institute	1996-1997
Member-at-Large, SAXS Special Interest Group, ACA	1997
International Advisory Committee, Synchrotron Radiation Instrumentation (SRI-2000)	1997
Dept. of Energy Basic Energy Sciences Advisory Subcommittee (Birgeneau Report)	1998
SLAC Scientific Policy Committee	1999-2002
International Union of Crystallography Commission on High Pressure	1998-2002
Chair, NSLS Scientific Advisory Committee	1999-2004
NRC Solid State Sciences Committee (Chair from 2001)	1999-2003
NRC Board of Assessment of NIST	1999-2002
International Union of Crystallography Commission on Synchrotron Radiation	1999-2008
Univ. Chicago APS Review Committee	2003
NSF MPS Scientific Advisory Committee	2004-2007

Scientific Council, DESY, Hamburg, Germany	2005-2007
Program Committee, ICFA workshop on future light sources	2009
SSRL Science Advisory Committee	2011-2013
European XFEL Detector Advisory Committee	2011-2013
Advisory Editorial Board, *Structural Dynamics*	2013-2018
Advisory Committee, Center for Exploration of Energy & Matter, Indiana Univ.	2014-2016
Helmholtz Organization, Germany, “From Matter to Materials and Life” review panel and vice-chair of the photon sub-panel	2014
NSLS-II Life Science and Biotechnology Res. Center	2014-

Patents:

S.M. Gruner and G. Kirk. Encapsulated scintillators for measuring the concentration of tritiated solutes. U.S. Patent #4,588,698 (5/13/86).

Robert P. Lenk, Michael W. Fountain, Andrew S. Janoff, Mircea C. Popescu, Steven J. Weiss, Richard S. Ginsgurg, Marc J. Ostro & Sol M. Gruner, Stable plurilamellar vesicles. US Pat. 5030453 - Filed Oct 12, 1984.

Robert P. Lenk, Michael W. Fountain, Andrew S. Janoff, Mircea C. Popescu, Steven J. Weiss, Richard S. Ginsgurg, Marc J. Ostro & Sol M. Gruner, Stable plurilamellar vesicles. US Pat. 5169637 - Filed Apr 2, 1991.

K. McGrath, D.M. Dabbs, I.A. Aksay, S.M. Gruner. Lyotropic liquid crystalline L_3 phase silicated nanoporous monolithic composites and their production. U.S. Patent # 6,638,885 (10/28/03).

Chae Un Kim & Sol M. Gruner, “Pressure Cryocooling Protein Crystals”, U.S. Patent 8030449 B2, granted Oct. 4, 2011.

Professional Societies:

American Physical Society
Biophysical Society
American Assoc. for Advancement of Science
American Crystallographic Assoc.
American Chemical Society
Materials Research Society

Publications & Students (as of end of 2014):

- Mentored 32 students through to the PhD, and 25 post-docs.
- Authored 310 publications. The Institute for Scientific Information lists >11,000 citations, and provides an h-index of 56; Google Scholar lists >14,400 citations and an h-index of 63.

Narrative: Major Research Thrusts & Accomplishments

Phase Behavior of Biomembrane Lipids

Studies on the phase behavior of biomembrane lipids occupied Gruner's attention through the decade of the 1980's. He was responsible for introducing concepts of elasticity from liquid crystal physics as applied to lipid monolayers to understand the mesomorphic behavior of lipid-water dispersions. Gruner and graduate student G. Kirk introduced the concept that lipid mesomorphic behavior may be understood as a frustrated system dominated by lipid monolayer spontaneous curvature and hydrocarbon chain packing. (Similar ideas were introduced independently at about the same time by J. Charvolin in France). In 1985 Gruner proposed that lipid monolayer spontaneous curvature is a homeostatically controlled parameter in biomembranes, and that monolayer elastic strain couples to membrane protein function [1]. He also studied lipid cubic phases and coined the widely used suggestive name "Plumbers Nightmare" for cubic phases of certain symmetry. In 1988, Gruner and colleagues showed how spontaneous curvature and chain packing can explain bicontinuous cubic phases in mesomorphic systems [2]. Much of the now commonly used language about lipid spontaneous curvature in the biophysical literature can be traced to Gruner's publications of this period. Much of this work is summarized in [3]. In 1990, Gruner was named a Fellow of the American Physical Society "For major contributions to the understanding of structure and function of biomembrnaes. His research has provided insight on the physical basis of lyotropic mesomorphism."

Block Co-Polymer Phase Behavior and Co-Polymer Based Synthesis of Complex Materials

In 1986 Gruner spent a sabbatical year at Exxon Research & Engineering and became interested in block copolymers. He realized that the same phenomenological physics that controlled lipid and surfactant phase behavior can be used to understand mesomorphism in block copolymers. Gruner and graduate student D. Hajduk began a series of systematic investigations of block co-polymer behavior using x-ray diffraction. In 1994 they discovered the gyroid morphology [4]. The concepts were later extended by Matsen and Bates others to explain copolymer phase diagrams [5]. This work set the stage for a rapid expansion of discoveries in block copolymer physics and materials science.

Gruner continues co-polymer investigations to the present day. Since coming to Cornell in 1997, he has collaborated with the Ober and Wiesner groups in Cornell's Materials Science & Engineering Department to study block copolymer-based synthesis of complex morphologies. These include morphologies where the block domains are chemically altered into metals and metal oxides, or chemically removed to create mesoporous structures. The work has been very productive, resulting in >33 publications and contributing to many Ph.D. projects (see http://bigbro.biophys.cornell.edu/publications/).

X-ray Detectors

Gruner has been working on the development of quantitative imaging x-ray detectors since his undergraduate thesis (1972), which was on the fabrication of one of the first silicon pixel array detectors for ionizing radiation detection. Early detectors at Princeton were based upon combinations of phosphors, image intensifiers and cooled imagers derived from astrophysics. In 1986 Gruner published on one of the first x-ray imagers using a CCD array [6]. In the early 1990's his group collaborated with CHESS to build and install the first CCD x-ray detector for macromolecular crystallographic data collection at a synchrotron facility. This device, which was based on phosphor films coupled to a cooled CCD via a fiber optic taper, catalyzed an exponential growth (literally) in macromolecular structure determination, and enabled experiments that would be difficult to otherwise perform. As example, a CCD detector constructed by Gruner's group was used by Rod MacKinnon (Rockefeller Univ.) to solve the structure of the K+ channel [7], which was listed by *Science* as one of the most important accomplishments of 1998, and which won the MacKinnon the Nobel prize in chemistry in 2003. As of this writing (2015) the majority of macromolecular structures deposited in the Protein Data Bank have been determined using CCD detectors utilizing technology first demonstrated in Gruner's laboratory. In 1999 Gruner was invited to summarize the development of these detectors at the American Crystallographic Society [8].

Emphasis has now shifted to silicon Pixel Array Detectors (PADs) in which x-rays are directly captured and the resultant signals processed in integrated circuit chips. Gruner's group designed and applied the world's first PADs for synchrotron science experiments. Personnel in the laboratory, including colleagues Drs. Mark Tate and Hugh Philipp, have specialized on integrating PADs (as opposed to photon counters) suitable for very fast time-resolved experiments. The lab is recognized as a world leader in this technology. These have been applied to, e.g., the study of gaseous shock waves, fuel injected aerosols, and phase transformation in reactive metal foils [9-13]. The group recently developed the PADs chips installed at experimental stations at the SLAC Linac Coherent Light Source, the world's first hard x-ray free electron laser. These have been used for a wide variety of experiments [14], including one cited by *Science* as one of the most important experiments of 2012 [15]. Several other PADs are in development for a wide variety of time-resolved synchrotron x-ray experiments. The technology is now being adapted for electron microscopy.

High Pressure Effects on Macromolecules

In the last 15 years members of Gruner's laboratory have studied the effects of hydrostatic pressure on biomacromolecular systems. Pressures of up to a few thousand atmospheres are present in the biosphere, and have long been known to have dramatic effects on numerous biomolecular systems. Few of these effects are understood. The approach that has been taken is to develop x-ray techniques to determine macromolecular structure at high pressure [16-18]. The effects of pressure turn out to lend considerable insight into the functioning of proteins and macromolecular systems. Some examples may be found in [18-21].

Synchrotron Radiation Technology and Science

As principle investigator and director of CHESS, Gruner had been privileged to influence synchrotron radiation science and technology. In 2001 he was named a Fellow of the American Association for the Advancement of Science "For pioneering contributions to the study of biological systems using advanced techniques of x-ray physics and for leadership in the development of synchrotron radiation instrumentation." Detectors and high-pressure x-ray techniques mentioned above are examples. Other examples are less apparent, but none the less significant, including fostering talent among colleagues at Cornell and CHESS to develop new technology. Examples include microfabricated flow cells [22], x-ray multilayers [23], and confocal x-ray microscopy as applied to works of art [24]. He was also principle investigator of Cornell's Energy Recovery Linac (ERL) project, which seeks to develop a novel type of diffraction limited synchrotron x-ray source [25].

In 2011 Gruner was elected to the American Academy of Arts and Sciences in recognition of his contributions.

1. Gruner, S.M., *Intrinsic curvature hypothesis for biomembrane lipid ccomposition: A Role for non-bilayer lipids.* Proc. Natl. Acad. Sci. USA, 1985. 82: p. 3665-3669.

2. Anderson, D., Gruner, S.M., Leibler, S., *Geometrical Aspects of the Frustration In The Cubic Phases of Lytropic Liquid Crystals.* Proc. Natl. Acad. Sci., 1988. 85: p. 5364-5368.

3. Gruner, S.M., *Stability of Lyotropic Phases with Curved Interfaces.* J. Phys. Chem., 1989. 93(22): p. 7562-7570.

4. Hajduk, D.A., Harper, P.E., Gruner, S.M., Honeker, C., Kim, G., Thomas, E.L., Fetters, L.J., *The gyroid: A new equilibrium morphology in weakly segregated diblock copolymers.* Macromol., 1994. 27: p. 4063-4075.

5. Matsen, M.W. and F.S. Bates, *Origins of complex self-assembly in block copolymers.* Macromolecules, 1996. 29(23): p. 7641-7644.

6. Eikenberry, E.F., S.M. Gruner, and J.L. Lowrance, *A Two-Dimensional X-Ray-Detector with a Slow-Scan Charge-Coupled Device Readout.* Ieee Transactions on Nuclear Science, 1986. 33(1): p. 542-545.

7. Doyle, D.A., et al., *The Structure of the Potassium Channel: Molecular Basis of K+ Conduction and Selectivity.* Science, 1998. 280: p. 69-77.

8. Gruner, S.M., *Synchrotron Radiation and Detectors: Synergists in a Dance.* Transactions ACA, 1999. 34: p. 11-25.

9. Cai, W.Y., et al., *Quantitative analysis of highly transient fuel sprays by time-resolved x-radiography.* Applied Physics Letters, 2003. 83(8): p. 1671-1673.

10. MacPhee, A.G., et al., *X-ray imaging of shock waves generated by high-pressure fuel sprays.* Science, 2002. 295(5558): p. 1261-1263.

11. Liu, X., et al., *Four dimensional visualization of highly transient fuel sprays by microsecond quantitative x-ray tomography.* Applied Physics Letters, 2009. 94(8): p. 084101-1.

12. Im, K.S., et al., *Interaction between Supersonic Disintegrating Liquid Jets and Their Shock Waves.* Physical Review Letters, 2009. 102(7): p. 074051-1.

13. Trenkle, J.C., et al., *Time-resolved x-ray microdiffraction studies of phase transformations during rapidly propagating reactions in Al/Ni and Zr/Ni multilayer foils.* Journal of Applied Physics, 2010. 107(11): p. 113511-1.

14. Boutet, S., et al., *High-Resolution Protein Structure Determination by Serial Femtosecond Crystallography.* Science, 2012. 337(6092): p. 362-364.

15. Koopmann, R., et al., *In vivo protein crystallization opens new routes in structural biology.* Nature Methods, 2012. 9(3): p. 259-U54.

16. Kim, C.U., et al., *Evidence for liquid water during the high-density to low-density amorphous ice transition.* Proceedings of the National Academy of Sciences of the United States of America, 2009. 106(12): p. 4596-4600.

17. Ando, N., et al., *Structural and thermodynamic characterization of T4 lysozyme mutants and the contribution of internal cavities to pressure denaturation.* Biochemistry, 2008. 47(42): p. 11097-11109.

18. Urayama, P., Phillips Jr., G.N., Gruner, S.M., *Probing Substates in Sperm Whale Myoglobin Using High-Pressure Crystallography.* Structure, 2002. 10: p. 51-60.

19. Barstow, B., et al., *Alteration of citrine structure by hydrostatic pressure explains the accompanying spectral shift.* Proceedings of the National Academy of Sciences of the United States of America, 2008. 105(36): p. 13362-13366.

20. Collins, M.D., et al., *Structural Rigidity of a Large Cavity-containing Protein Revealed by High-pressure Crystallography*, 2007. p. 752-763.

21. Ando, N., et al., *Pressure unfolding of a large cavity mutant of T4 Lysozyme.* Biophysical Journal, 2007: p. 400a-400a.

22. Pollack, L., et al., *Compactness of the denatured state of a fast-folding protein measured by submillisecond small-angle x-ray scattering.* Proc. Natl. Acad. Sci. USA, 1999. 96: p. 10115-10117.

23. Kazimirov, A., et al., *Multilayer X-ray optics at CHESS.* Journal of Synchrotron Radiation, 2006. 13: p. 204-210.

24. Woll, A.R., et al., *Development of confocal X-ray fluorescence (XRF) microscopy at the Cornell high energy synchrotron source.* Applied Physics a-Materials Science & Processing, 2006. 83(2): p. 235-238.

25. Bilderback, D.H., et al., *Energy recovery linac (ERL) coherent hard x-ray sources.* New Journal of Physics, 2010. 12: p. 035011.