Summary of Results

The main objective of this grant was to develop the theory for a new grain alignment mechanism, "grain alignment by ambipolar diffusion," which was discovered by us and which may be relevant to observations of far-infrared polarization toward the Galactic center and elsewhere. We have accomplished this goal, published the results, and carried out a number of "spinoff investigations." These results have been disseminated at several meetings, including an international conference, *Polarimetry of the ISM*, that was co-organized by Roberge and Whittet.

1. Theory of Grain Alignment by Ambipolar Diffusion

In collaboration with T. DeGraff and J. Flaherty (RPI), I developed an accurate mathematical technique for solving a broad class of problems in grain alignment theory. In collaboration with S. Hanany (UC Berkeley) and D. Messinger (RPI), I demonstrated that the grains in a dusty plasma undergoing supersonic ambipolar diffusion will be aligned by collisions with steaming gas molecules. This work also predicts the far-infrared polarization that can be observed (e.g., from SOFIA) due to this effect. In collaboration with S. Desch (Illinois), I showed that one can obtain a good model for the far-infrared polarization observed by Hildebrand's group toward the Galactic circumnuclear disk if one assumes that the grains are aligned by ambipolar diffusion.

2. Models of the Infrared Polarization in the Water-Ice Band

As a spinoff to the Project 1, we are modeling the near-infrared polarizations observed in the water-ice feature toward BN and other young stellar objects. These models provide invaluable information about the structure and composition of ices in different physical environments.

3. Physics of Grain Alignment

A. Lazarian (Princeton) and I have begun an ambitious collaboration that will ultimately yield quantitative predictions for all of the grain alignment mechanisms (Davis-Greenstein, Gold's Mechanism, ambipolar diffusion, and alignment by radiative torques). We have published a paper on the physics of Barnett relaxation. We have submitted a paper on the possible effects of cosmic rays on grain alignment. At least 3 more submissions are expected this year.

Publications

1. Invited Review and Proceedings Edited

1. Roberge, W. G. 1996, "Grain Alignment in Molecular Clouds," invited review in *Polarimetry of the ISM*, eds. W.G. Roberge and D.C.B. Whittet, ASP Conference Series, Vol. 97, p. 401 (1996).

2. Roberge, W.G., & Whittet, D.C.B., eds. 1996, *Polarimetry of the Interstellar Medium*, proceedings of an international symposium held at Rensselaer, ASP Conference Series, Vol. 97, 633pp. (1996).

2. Articles in Refereed Journals

1. Desch, S.J., & Roberge, W.G. 1997, "Ambipolar Diffusion and Far-Infrared Polarization from the Galactic Circumnuclear Disk," ApJ, 475, L115

2. Hough, J.H., Chrysostomou, A., Messinger, D.W., Whittet, D.C.B., Aitken, D.K., & Roche, P.F. 1996, "Spectropolarimetry of the 3 Micron Ice Feature Toward the BN Object," ApJ, 461, 902

3. Lazarian, A., & Roberge, W.G. 1997, "Barnett Relaxation in Thermally-Rotating Grains," ApJ, accepted

4. Lazarian, A., & Roberge, W.G. 1997, "Cosmic Rays and Grain Alignment," MNRAS, submitted

5. Messinger, D.W., Whittet, D.C.B., & Roberge, W.G., 1997, "Interstellar Extinction and Polarization in the Taurus Dark Clouds, I. Wavelength Dependent Position Angles of Polarization and Cloud Structure Near TMC-1," to be submitted.

6. Roberge, W.G., DeGraff, T.A., and Flaherty, J.E. 1993, "The Langevin Equation and its Application to Grain Alignment in Molecular Clouds," ApJ, 418, 287

7. Roberge, W. G., Hanany, S., and Messinger, D.W. 1995, "Grain Alignment by Ambipolar DIffusion in Molecular Clouds," ApJ, 453, 238

3. Nonrefereed Publications

1. Desch, S.J., & Roberge, W.G. 1996, "Infrared Polarization in the Molecular Disk at the Galactic Center," in *Polarimetry of the ISM*, eds. W.G. Roberge and D.C.B. Whittet, ASP Conference Series, Vol. 97, p. 450.

2. Karcz, J.S., & Roberge, W.G., "Implications from Spectropolarimetry of the 2175 Å Extinction Feature," in *Polarimetry of the ISM*, eds. W.G. Roberge and D.C.B. Whittet, ASP Conference Series, Vol. 97, p. 445 (1996).

3. Messinger, D.W., Roberge, W.G., & Hanany, S. 1994, "Ambipolar Diffusion and Polarized Thermal Emission from Dust," in *Clouds, Cores, and Low Mass Stars*, ed. D. Clemens and R. Barvainis (San Francisco: Astronomical Society of the Pacific), p. 156

4. Messinger, D.W., Roberge, W. G., & Hanany, S. 1996, "Grain Alignment by Ambipolar Diffusion in Molecular Clouds," in *Polarimetry of the ISM*, eds. W.G. Roberge and D.C.B. Whittet, ASP Conference Series, Vol. 97, p. 443 (1996).

5. Messinger, D.W., Roberge, W.G., Whittet, D.C.B., Chrysostomou, A., & Hough, J.H., "Modeling New Spectropolarimetry Data for the BN Object," in *Polarimetry of the ISM*, eds. W.G. Roberge and D.C.B. Whittet, ASP Conference Series, Vol. 97, p. 249 (1996).

6. Roberge, W.G., DeGraff, T.A., & J.E. Flaherty, 1992, "Super-Paramagnetic Alignment of Core-Mantle Grains," BAAS, Vol. 24, No. 4, p. 1121.

7. Roberge, W.G., & Hanany, S. 1993, "Ambipolar Diffusion and Polarized Thermal Emission from Dust," BAAS, 25, No. 4, p. 1312

8. Roberge, W.G., DeGraff, T.A., & Flaherty, J.E. 1996, "Paramagnetic Alignment of Molecular Cloud Grains," in *Polarimetry of the ISM*, eds. W.G. Roberge and D.C.B. Whittet, ASP Conference Series, Vol. 97, pp. 401–418 (1996).