ALC BOOK DAME OF THE CARGENCY INTEGENT IN PROPENDING AND ADDRESS (F) INTEGENT ADDRESS (F) INTEGENT ADDRESS (F) INTEGENT ADDRESS (F) INTEGENT		REPORT DC	CUMENTATI	ON PAGE	AFF	RL-SR-AR-TR-04-	
1. REPORT DATE (DO-MAY YYY) 2. REPORT TYPE 1. REPORT TYPE 1. March 29, 2004 1. SATES 2004 1. SATES 2004 4. TITLE AND SUBTITLE 5. CONTRACT NUMBER Fendosecond Dynamics of Chemical Reactions 5. CRAIT NUMBER 6. AUTHOR(S) 5. CRAIT NUMBER Dr. Ahmed H. Zewail 200040423 021 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) California Institute of 1200 East California Blvd., M/C California Blvd., M/C SPONSORING /MONTORING AGENCY NAME(S) AND ADDRESS(ES) California Blvd., Room 713 Research Arrington VA 22203-1954 1. SPONSORMONTORIS AGENCY NAME(S) AND ADDRESS(ES) California Blvd., Room 713 Research Arrington VA 22203-1954 1. SPONSORMONTOR'S REPORT NUMBER Is SPONSORMONTOR'S AGENCY NAME(S) AND ADDRESS(ES) Arrington VA 22203-1954 1. SPONSORMONTOR'S REPORT NUMBER Is SPONSORMONTOR'S REPORT NUMBER <td colspan<="" th=""><th>data needed, and completin this burden to Department (4302 Respondents should</th><th>ng and reviewing this collection of Defense, Washington Heado the aware that notwithstanding</th><th>of information. Send comments quarters Services, Directorate for I any other provision of law, no pe</th><th>regarding this burden estimate or ar Information Opersticns and Reports Irson shell be subject to any penalty</th><th>1y other aspect (0704-0188),</th><th>0202</th></td>	<th>data needed, and completin this burden to Department (4302 Respondents should</th> <th>ng and reviewing this collection of Defense, Washington Heado the aware that notwithstanding</th> <th>of information. Send comments quarters Services, Directorate for I any other provision of law, no pe</th> <th>regarding this burden estimate or ar Information Opersticns and Reports Irson shell be subject to any penalty</th> <th>1y other aspect (0704-0188),</th> <th>0202</th>	data needed, and completin this burden to Department (4302 Respondents should	ng and reviewing this collection of Defense, Washington Heado the aware that notwithstanding	of information. Send comments quarters Services, Directorate for I any other provision of law, no pe	regarding this burden estimate or ar Information Opersticns and Reports Irson shell be subject to any penalty	1y other aspect (0704-0188),	0202
ATTLE AND SUBTITLE Encode Femtosecond Dynamics of Chemical Reactions Encode Contract Number Se GRAT MUMBER Encode Contract Number Se ADTHOR(S) Dr. Ahmed H. Zewail Dr. Ahmed H. Zewail 200040423 021 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Image: Contract Number California Institute of 1200 East California Blvd., M/C Technology 127-72, Pasadena, CA 91125 S. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Image: Contract Number S. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Image: Contract Number S. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Image: Contract Number S. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Image: Contract Number S. BORNSOR/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Image: Contract Number S. BORNSOR/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Image: Contract Number Artington VA 22203-1954 Image: Contract Number 12. DISTRIBUTION / AVAILABILITY STATEMENT Number PAQPROVE For Public Release: Distribution Unlimited 13. SUPPLEMENTARY NOTES Image: Contract Number 14. ABSTRACT We proposed to use this grant to undertake research in the following	1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE				
Pentosecond Dynamics of Chemical Reactions Sb. GRANT NUMBER P49620-98-1-0059 Sc. PROGRAM ELEMENT NUMBER Author(s) Dr. Ahmed H. Zewail 200404230021 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) California Institute of 1200 East California Blvd., M/C Steponsoprind/MONTORING AGENCY NAME(S) AND ADDRESS(ES) California Institute of 1207-72, Pasadena, CA 91125 Steponsoprind/MONTORING AGENCY NAME(S) AND ADDRESS(ES) AP Office of Scientific 4015 Wilson Blvd., Room 713 Research Arlington VA 22203-1954 10. SPONSORMONTOR'S ACRONYMER USAF, AFRL 11. SponsorMONTOR'S REPORT NUMBER(S) 12. DISTRIBUTION / AVAILABILITY STATEMENT Approve For Public Release: Distribution Unlimited 13. SUPPLEMENTARY NOTES 14. ABSTRACT We proposed to use this grant to undertake research in the following three major areas: (a) Dynamics of elementary steps in complex systems. (b) Dynamics of oreactions under extreme environment (density, temperature, clustering, etc.). (c) New techniques for direct imaging of structural changes and chemical control of reactions yield and channel. In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular betechniques to examine in real time the nature of the dynamics and structures on the fentosecond time scale. Our goal was are key to validating any model of chemical reactivity in complex molecular systems. Theoretical studies in our group and in collaboration with			Final				
			nemical Reaction	ns			
S. AUTHOR(S) Dr. Ahmed H. Zewail California Institute of 1200 East California Blvd., M/C California Institute of 1200 Cast California Blvd., Room 713 California Cast California Cast California Cast California Blvd., M/C California Cast California Cast California Cast California Blvd., M/C California Cast Ca		-					
AUTHOR(S) Dr. Ahmed H. Zewail 20040423 021 2020 20040423 021 2020							
Dr. Ahmed H. Zewail 200040423 021 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) California Institute of 1200 East California Blvd., M/C Technology 127-72, Pasadena, CA 91125 8. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) AF Office of Scientific 4015 Wilson Blvd., Room 713 AF Office of Scientific 4015 Wilson Blvd., Room 713 Research Arlington VA 22203-1954 11. SPONSORMONITOR'S ACRONYM(S) 12. DISTRIBUTION / AVAILABILITY STATEMENT Approve For Public Release: Distribution Unlimited 13. SUPPLEMENTARY NOTES 14. ABSTRACT We proposed to use this grant to undertake research in the following three major areas: (a) Dynamics of elementary steps in complex systems. (b) Dynamics of reactions under extreme environment (density, temperature, clustering, etc.). (c) New techniques for direct imaging of structural changes and chemical control of reactions yield and channel. In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular bezed to examine in real time the nature of the dynamics and structures on the femtosecond time scale. Our goal was relate these dynamics to features of bonding and mechanisms and to explore the effect of extreme solvation environment (reactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex into and the collaboration with colleagues elsewhere were an important par 16. SUBJECT TERMS					50.	. PROGRAM ELEMENT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) • FERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) California Institute of 1200 East California Blvd., M/C Technology 127-72, Pasadena, CA 91125 6. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) 10. SPONSORMONITOR'S ACRONYM(S) AP Office of Scientific 4015 Wilson Blvd., Room 713 Research Arlington VA 22203-1954 11. SPONSORMONITOR'S ACRONYM(S) 12. DISTRIBUTION / AVAILABULITY STATEMENT Approve For Public Release: Distribution Unlimited. 13. SUPPLEMENTARY NOTES 14. ABSTRACT We proposed to use this grant to undertake research in the following three major areas: (a) Dynamics of elementary steps in complex systems. (b) Dynamics of reactions under extreme environment (density, temperature, clustering, etc.). (c) New techniques for direct imaging of structural changes and chemical control of reactions yield and channel. In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular bezetoniques to features of bonding and mechanisms and structures on the femtosecond time scale. Our goal was and to explore the effect of extreme solvation environment or reactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex molecular systems. Theoretical studies in our group and in collaboration with colleagues elsewhere were		wail			_		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) California Institute of 1200 East California Blvd., M/C 127-72, Pasadena, CA 91125 9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) 10. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) AF Office of Scientific 4015 Wilson Blvd., Room 713 Research Arlington VA 22203-1954 11. SPONSORMONITOR'S REPORT NUMBER(S) 12. DISTRIBUTION / AVAILABILITY STATEMENT Approve For Public Release: Distribution Unlimited - 13. SUPPLEMENTARY NOTES 14. ABSTRACT We proposed to use this grant to undertake research in the following three major areas: (a) Dynamics of elementary steps in complex systems. (b) Dynamics of reactions under extreme environment (density, temperature, clustering, etc.). (c) New techniques for direct imaging of structural changes and chemical control of reactions yield and channel. In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular beze techniques to features of bonding and mechanisms and to explore the effect of extreme solvation environment or reactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in romplex molecular beze in molecular beze in these studies in our group and in collaboration with colleagues elsewhere were an important par 16. SUBJECT TEMS							
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) California Institute of 1200 East California Blvd., M/C 127-72, Pasadena, CA 91125 9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) 10. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) AF Office of Scientific 4015 Wilson Blvd., Room 713 Research Arlington VA 22203-1954 11. SPONSORMONITOR'S REPORT NUMBER(S) 12. DISTRIBUTION / AVAILABILITY STATEMENT Approve For Public Release: Distribution Unlimited - 13. SUPPLEMENTARY NOTES 14. ABSTRACT We proposed to use this grant to undertake research in the following three major areas: (a) Dynamics of elementary steps in complex systems. (b) Dynamics of reactions under extreme environment (density, temperature, clustering, etc.). (c) New techniques for direct imaging of structural changes and chemical control of reactions yield and channel. In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular beze techniques to features of bonding and mechanisms and to explore the effect of extreme solvation environment or reactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in romplex molecular beze in molecular beze in these studies in our group and in collaboration with colleagues elsewhere were an important par 16. SUBJECT TEMS					20	060625 021	
California Institute of I200 East California Blvd., M/C Technology 127-72, Pasadena, CA 91125 S. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) AF Office of Scientific AF Office of Scientific Arlington VA 22203-1954 11. SPONSORMONITOR'S ACRONYM(S) 12. DISTRIBUTION / AVAILABILITY STATEMENT Approve For Public Release: Distribution Unlimited 13. SUPPLEMENTARY NOTES 14. ABSTRACT We proposed to use this grant to undertake research in the following three major areas: (a) Dynamics of elementary steps in complex systems. (b) Dynamics of reactions under extreme environment (density, temperature, clustering, etc.). (c) New techniques for direct imaging of structural changes and chemical control of reactions yield and channel. In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular bear techniques to features of bonding and mechanisms and to explore the effect of extreme solvation environment or reactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex reactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex or provement in our group and in collaboration with colleagues elsewhere were an important par 15. SUBJECT TERMS					2 V	VAVALS VLI	
California Institute of T200 East California Blvd., M/C Technology NUMBER 9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) 10. SPONSOR/MONITOR'S ACRONYM(S) AF Office of Scientific 4015 Wilson Blvd., Room 713 Research Arlington VA 22203-1954 11. SPONSOR/MONITOR'S REPORT NUMBER(S) 12. DISTRIBUTION / AVAILABILITY STATEMENT Approve For Public Release: Distribution Unlimited 13. SUPPLEMENTARY NOTES 14. ABSTRACT (a) Dynamics of elementary steps in complex systems. (b) Dynamics of reactions under extreme environment (density, temperature, clustering, etc.). (c) New techniques for direct imaging of structural changes and chemical control of reactions yield and channel. In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular best techniques to features of bonding and mechanisms and to explore the effect of extreme solvation environment or reactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular best techniques to features of bonding and mechanisms and to explore the effect of extreme solvation environment or reactivity. Probing an controlling reactions pathways are key to validating any model of chemical reactivity in complex 14. ABSTRACT Subject TERMS <td>7. PERFORMING O</td> <td>RGANIZATION NAME</td> <td>(S) AND ADDRESS(ES)</td> <td></td> <td></td> <td></td>	7. PERFORMING O	RGANIZATION NAME	(S) AND ADDRESS(ES)				
Technology 127-72, Pasadena, CA 91125 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) AF Office of Scientific 4015 Wilson Blvd., Room 713 Arlington VA 22203-1954 10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S ACRONYM(S) 12. DISTRIBUTION / AVAILABILITY STATEMENT Approve For Public Release: Distribution Unlimited 13. SUPPLEMENTARY NOTES 14. ABSTRACT We proposed to use this grant to undertake research in the following three major areas: (a) Dynamics of elementary steps in complex systems. (b) Dynamics of elementary steps in complex systems. (c) New techniques for direct imaging of structural changes and chemical control of reactions yield and channel. In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular bechniques to examine in real time the nature of the dynamics and structures on the femtosecond time scale. Our goal was relate these dynamics to features of bonding and mechanisms and to explore the effect of extreme solvation environment creactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex molecular systems. Theoretical studies in our group and in collaboration with colleagues elsewhere were an important par 15. SUBJECT TERMS						NUMBER	
 a. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) AF Office of Scientific 4015 Wilson Blvd., Room 713 Arlington VA 22203-1954 10. SPONSOR/MONITOR'S ACRONYM(S USAF, AFRL 11. SPONSOR/MONITOR'S ACRONYM(S) USAF, AFRL 11. SPONSOR/MONITOR'S REPORT NUMBER(S) 12. DISTRIBUTION / AVAILABILITY STATEMENT Approve For Public Release: Distribution Unlimited. 13. SUPPLEMENTARY NOTES 14. ABSTRACT We proposed to use this grant to undertake research in the following three major areas: (a) Dynamics of elementary steps in complex systems. (b) Dynamics of reactions under extreme environment (density, temperature, clustering, etc.). (c) New techniques for direct imaging of structural changes and chemical control of reactions yield and channel. In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular beat techniques to features of bonding and mechanisms and to explore the effect of extreme solvation environment or reactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex systems. Theoretical studies in our group and in collaboration with colleagues elsewhere were an important par 15. SUBJECT TERMS 		nstitute OI					
AF Office of Scientific 4015 Wilson Blvd., Room 713 Arlington VA 22203-1954 USAF, AFRL 11. SPONSOR/MONITOR'S REPORT NUMBER(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S) 12. DISTRIBUTION / AVAILABILITY STATEMENT Distribution Unlimited 13. SUPPLEMENTARY NOTES 13. SUPPLEMENTARY NOTES 14. ABSTRACT We proposed to use this grant to undertake research in the following three major areas: (a) Dynamics of elementary steps in complex systems. (b) Dynamics of reactions under extreme environment (density, temperature, clustering, etc.). (c) New techniques for direct imaging of structural changes and chemical control of reactions yield and channel. In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular bear relate these dynamics to features of bonding and mechanisms and to explore the effect of extreme solvation environment or exactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex molecular systems. Theoretical studies in our group and in collaboration with colleagues elsewhere were an important par 16. SUBJECT TEMS	10011101031			·			
AF Office of Scientific 4015 Wilson Blvd., Room 713 Arlington VA 22203-1954 USAF, AFRL 11. SPONSOR/MONITOR'S REPORT NUMBER(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S) 12. DISTRIBUTION / AVAILABILITY STATEMENT Distribution Unlimited 13. SUPPLEMENTARY NOTES 13. SUPPLEMENTARY NOTES 14. ABSTRACT We proposed to use this grant to undertake research in the following three major areas: (a) Dynamics of elementary steps in complex systems. (b) Dynamics of reactions under extreme environment (density, temperature, clustering, etc.). (c) New techniques for direct imaging of structural changes and chemical control of reactions yield and channel. In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular bear relate these dynamics to features of bonding and mechanisms and to explore the effect of extreme solvation environment or exactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex molecular systems. Theoretical studies in our group and in collaboration with colleagues elsewhere were an important par 16. SUBJECT TEMS							
AF Office of Scientific 4015 Wilson Blvd., Room 713 Arlington VA 22203-1954 USAF, AFRL 11. SPONSOR/MONITOR'S REPORT NUMBER(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S) 12. DISTRIBUTION / AVAILABILITY STATEMENT Poprove For Public Release: Distribution Unlimited 13. SUPPLEMENTARY NOTES 14. ABSTRACT (a) Dynamics of elementary steps in complex systems. (b) Dynamics of reactions under extreme environment (density, temperature, clustering, etc.). (c) New techniques for direct imaging of structural changes and chemical control of reactions yield and channel. In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular becalite these dynamics to features of bonding and mechanisms and to explore the effect of extreme solvation environment or exactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex molecular systems. Theoretical studies in our group and in collaboration with colleagues elsewhere were an important par 16. SUBJECT TEMS	A SPONSORING /	MONITORING AGENC			10	SPONSOR/MONITOR'S ACRONYM(S)	
 11. SPONSORMONITOR'S REPORT NUMBER(S) 12. DISTRIBUTION / AVAILABILITY STATEMENT Approve For Public Release: Distribution Unlimited 13. SUPPLEMENTARY NOTES 14. ABSTRACT We proposed to use this grant to undertake research in the following three major areas: (a) Dynamics of elementary steps in complex systems. (b) Dynamics of elementary steps in complex systems. (c) New techniques for direct imaging of structural changes and chemical control of reactions yield and channel. In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular bee techniques to examine in real time the nature of the dynamics and structures on the femtosecond time scale. Our goal was relate these dynamics to features of bonding and mechanisms and to explore the effect of extreme solvation environment complex systems. Theoretical studies in our group and in collaboration with colleagues elsewhere were an important par 15. SUBJECT TERMS 			4015 Wils	on Plud Boom			
NUMBER(S) 12. DISTRIBUTION / AVAILABILITY STATEMENT Approve For Public Release: Distribution Unlimited 13. SUPPLEMENTARY NOTES 14. ABSTRACT We proposed to use this grant to undertake research in the following three major areas: (a) Dynamics of elementary steps in complex systems. (b) Dynamics of reactions under extreme environment (density, temperature, clustering, etc.). (c) New techniques for direct imaging of structural changes and chemical control of reactions yield and channel. In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular ber techniques to examine in real time the nature of the dynamics and structures on the femtosecond time scale. Our goal was relate these dynamics to features of bonding and mechanisms and to explore the effect of extreme solvation environment to reactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex molecular systems. Theoretical studies in our group and in collaboration with colleagues elsewhere were an important par 15. SUBJECT TERMS							
 12. DISTRIBUTION / AVAILABILITY STATEMENT Approve For Public Release: Distribution Unlimited. 13. SUPPLEMENTARY NOTES 14. ABSTRACT We proposed to use this grant to undertake research in the following three major areas: (a) Dynamics of elementary steps in complex systems. (b) Dynamics of reactions under extreme environment (density, temperature, clustering, etc.). (c) New techniques for direct imaging of structural changes and chemical control of reactions yield and channel. In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular beat relate these dynamics to features of bonding and mechanisms and to explore the effect of extreme solvation environment or reactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex molecular systems. Theoretical studies in our group and in collaboration with colleagues elsewhere were an important par 15. SUBJECT TERMS 	Research						
 Approve For Public Release: Distribution Unlimited. 13. SUPPLEMENTARY NOTES 14. ABSTRACT We proposed to use this grant to undertake research in the following three major areas: (a) Dynamics of elementary steps in complex systems. (b) Dynamics of reactions under extreme environment (density, temperature, clustering, etc.). (c) New techniques for direct imaging of structural changes and chemical control of reactions yield and channel. In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular bere techniques to examine in real time the nature of the dynamics and structures on the femtosecond time scale. Our goal was relate these dynamics to features of bonding and mechanisms and to explore the effect of extreme solvation environment or reactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex molecular systems. Theoretical studies in our group and in collaboration with colleagues elsewhere were an important par 15. SUBJECT TERMS 	Research					SPONSOR/MONITOR'S REPORT	
 We proposed to use this grant to undertake research in the following three major areas: (a) Dynamics of elementary steps in complex systems. (b) Dynamics of reactions under extreme environment (density, temperature, clustering, etc.). (c) New techniques for direct imaging of structural changes and chemical control of reactions yield and channel. In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular beat techniques to examine in real time the nature of the dynamics and structures on the femtosecond time scale. Our goal was relate these dynamics to features of bonding and mechanisms and to explore the effect of extreme solvation environment or reactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex molecular systems. Theoretical studies in our group and in collaboration with colleagues elsewhere were an important par 15. SUBJECT TERMS 		AVAILABILITY STAT	Arlingtor	1 VA 22203-1954	11.	SPONSOR/MONITOR'S REPORT NUMBER(S)	
 (a) Dynamics of elementary steps in complex systems. (b) Dynamics of reactions under extreme environment (density, temperature, clustering, etc.). (c) New techniques for direct imaging of structural changes and chemical control of reactions yield and channel. In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular beat techniques to examine in real time the nature of the dynamics and structures on the femtosecond time scale. Our goal was relate these dynamics to features of bonding and mechanisms and to explore the effect of extreme solvation environment or reactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex molecular systems. Theoretical studies in our group and in collaboration with colleagues elsewhere were an important par 15. SUBJECT TERMS 	12. DISTRIBUTION Approve 7	TAVAILABILITY STAT FOR PUBLIC R	Arlingtor	1 VA 22203-1954	11.	SPONSOR/MONITOR'S REPORT NUMBER(S)	
 (a) Dynamics of elementary steps in complex systems. (b) Dynamics of reactions under extreme environment (density, temperature, clustering, etc.). (c) New techniques for direct imaging of structural changes and chemical control of reactions yield and channel. In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular beat techniques to examine in real time the nature of the dynamics and structures on the femtosecond time scale. Our goal was relate these dynamics to features of bonding and mechanisms and to explore the effect of extreme solvation environment or reactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex molecular systems. Theoretical studies in our group and in collaboration with colleagues elsewhere were an important par 15. SUBJECT TERMS 	12. DISTRIBUTION Approve 7 13. supplementa	TAVAILABILITY STAT FOR PUBLIC R	Arlingtor	1 VA 22203-1954	11.	SPONSOR/MONITOR'S REPORT NUMBER(S)	
 (b) Dynamics of reactions under extreme environment (density, temperature, clustering, etc.). (c) New techniques for direct imaging of structural changes and chemical control of reactions yield and channel. In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular beat techniques to examine in real time the nature of the dynamics and structures on the femtosecond time scale. Our goal was relate these dynamics to features of bonding and mechanisms and to explore the effect of extreme solvation environment or reactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex molecular systems. Theoretical studies in our group and in collaboration with colleagues elsewhere were an important par 15. SUBJECT TERMS 	12. DISTRIBUTION Approve 7 13. SUPPLEMENTA 14. ABSTRACT	TAVAILABILITY STAT For Public R ARY NOTES	Arlingtor FEMENT elease: Dist	n VA 22203-1954	11. limited -	SPONSOR/MONITOR'S REPORT NUMBER(S)	
(c) New techniques for direct imaging of structural changes and chemical control of reactions yield and channel. In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular beat techniques to examine in real time the nature of the dynamics and structures on the femtosecond time scale. Our goal was relate these dynamics to features of bonding and mechanisms and to explore the effect of extreme solvation environment of reactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex molecular systems. Theoretical studies in our group and in collaboration with colleagues elsewhere were an important par 15. SUBJECT TERMS	12. DISTRIBUTION Approve 7 13. SUPPLEMENTA 14. ABSTRACT	TAVAILABILITY STAT For Public R ARY NOTES	Arlingtor FEMENT elease: Dist	n VA 22203-1954	11. limited -	SPONSOR/MONITOR'S REPORT NUMBER(S)	
In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular beat techniques to examine in real time the nature of the dynamics and structures on the femtosecond time scale. Our goal was relate these dynamics to features of bonding and mechanisms and to explore the effect of extreme solvation environment or reactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex molecular systems. Theoretical studies in our group and in collaboration with colleagues elsewhere were an important par 15. SUBJECT TERMS	12. DISTRIBUTION Approve 7 13. SUPPLEMENTA 14. ABSTRACT We prop (a) Dynami	TAVAILABILITY STAT FOF PUBLIC R ARY NOTES	Arlingtor TEMENT elease: Distr rant to undertake res	earch in the following	timited g three major a	areas:	
techniques to examine in real time the nature of the dynamics and structures on the femtosecond time scale. Our goal was relate these dynamics to features of bonding and mechanisms and to explore the effect of extreme solvation environment or reactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex molecular systems. Theoretical studies in our group and in collaboration with colleagues elsewhere were an important par 15. SUBJECT TERMS	12. DISTRIBUTION APPROVE 7 13. SUPPLEMENTA 14. ABSTRACT We prop (a) Dynami (b) Dynami	TAVAILABILITY STAT FOF PUBLIC R ARY NOTES	Arlingtor REMENT elease: Distri rant to undertake res reps in complex syste ler extreme environr	ems. nent (density, temper	g three major a	areas:	
techniques to examine in real time the nature of the dynamics and structures on the femtosecond time scale. Our goal was relate these dynamics to features of bonding and mechanisms and to explore the effect of extreme solvation environment or reactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex molecular systems. Theoretical studies in our group and in collaboration with colleagues elsewhere were an important par 15. SUBJECT TERMS	12. DISTRIBUTION APPROVE 7 13. SUPPLEMENTA 14. ABSTRACT We prop (a) Dynami (b) Dynami	TAVAILABILITY STAT FOF PUBLIC R ARY NOTES	Arlingtor REMENT elease: Distri rant to undertake res reps in complex syste ler extreme environr	ems. nent (density, temper	g three major a	areas:	
relate these dynamics to features of bonding and mechanisms and to explore the effect of extreme solvation environment or reactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex molecular systems. Theoretical studies in our group and in collaboration with colleagues elsewhere were an important par 15. SUBJECT TERMS	12. DISTRIBUTION Approve 7 13. SUPPLEMENTA 14. ABSTRACT We prop (a) Dynami (b) Dynami (c) New tec	AVAILABILITY STAT For Public R ARY NOTES posed to use this gr cs of elementary st cs of reactions und chniques for direct	Arlingtor	earch in the following ems. nent (density, temper al changes and chemic	g three major a ature, clusteri cal control of r	areas: ng, etc.). eactions yield and channel.	
molecular systems. Theoretical studies in our group and in collaboration with colleagues elsewhere were an important par 15. SUBJECT TERMS	12. DISTRIBUTION APPROVE 7 13. SUPPLEMENTA 14. ABSTRACT We prop (a) Dynami (b) Dynami (c) New teo In these techniques to ex	AVAILABILITY STAT For Public R ARY NOTES posed to use this gr acs of elementary st cs of reactions und chniques for direct studies, the basic a amine in real time	Arlingtor	earch in the following ems. nent (density, temper al changes and chemic n the development of a namics and structures	g three major a ature, clusterin cal control of r ultrafast laser s on the femtor	Areas: ng, etc.). reactions yield and channel. (and electron) and molecular bea second time scale. Our goal was	
15. SUBJECT TERMS	12. DISTRIBUTION Approve 7 13. SUPPLEMENTA 14. ABSTRACT We prop (a) Dynami (b) Dynami (c) New teo In these techniques to ex relate these dyna	AVAILABILITY STAT For Public R ARY NOTES cosed to use this gr cs of elementary st cs of reactions und chniques for direct studies, the basic a amine in real time amics to features o	Arlingtor	ems. In the following ems. In changes and chemic in the development of mamics and structures anisms and to explore	g three major a ature, clusterin cal control of r ultrafast laser s on the femtor e the effect of o	SPONSOR/MONITOR'S REPORT NUMBER(S) areas: ng, etc.). reactions yield and channel. (and electron) and molecular bea second time scale. Our goal was extreme solvation environment or	
	12. DISTRIBUTION Approve 7 13. SUPPLEMENTA 14. ABSTRACT We prop (a) Dynami (b) Dynami (c) New teo In these techniques to ex relate these dyna reactivity. Probin	AVAILABILITY STAT For Public R ARY NOTES cosed to use this gr cs of elementary st cs of reactions und chniques for direct studies, the basic a amine in real time amics to features o ng and controlling	Arlingtor	t VA 22203-1954 wearch in the following tems. nent (density, temper al changes and chemic the development of the namics and structures anisms and to explore are key to validating	g three major a ature, clusterir cal control of r ultrafast laser s on the femtor e the effect of e any model of	areas: ng, etc.). eactions yield and channel. (and electron) and molecular bea second time scale. Our goal was extreme solvation environment or chemical reactivity in complex	
16 SECURITY CLASSIFICATION OF	12. DISTRIBUTION APPTOVE F 13. SUPPLEMENTA 14. ABSTRACT We prop (a) Dynami (b) Dynami (c) New tec In these techniques to ex relate these dyna reactivity. Probin molecular system	AVAILABILITY STAT To Public R ARY NOTES posed to use this gr acs of elementary st cs of reactions und chniques for direct studies, the basic a amine in real time amics to features o ng and controlling ms. Theoretical stud	Arlingtor	t VA 22203-1954 wearch in the following tems. nent (density, temper al changes and chemic the development of the namics and structures anisms and to explore are key to validating	g three major a ature, clusterir cal control of r ultrafast laser s on the femtor e the effect of e any model of	areas: ng, etc.). eactions yield and channel. (and electron) and molecular bea second time scale. Our goal was extreme solvation environment or chemical reactivity in complex	
TK SECORD Y CLASSIFICATION OF 177. LIMITATION 118. NUMBER 1138. NAME OF RESPONSIBLE FER	12. DISTRIBUTION APPTOVE 7 13. SUPPLEMENTA 14. ABSTRACT We prop (a) Dynami (b) Dynami (c) New tec In these techniques to ex relate these dyna reactivity. Probin molecular system	AVAILABILITY STAT To Public R ARY NOTES posed to use this gr acs of elementary st cs of reactions und chniques for direct studies, the basic a amine in real time amics to features o ng and controlling ms. Theoretical stud	Arlingtor	t VA 22203-1954 wearch in the following tems. nent (density, temper al changes and chemic the development of the namics and structures anisms and to explore are key to validating	g three major a ature, clusterir cal control of r ultrafast laser s on the femtor e the effect of e any model of	areas: ng, etc.). eactions yield and channel. (and electron) and molecular bea second time scale. Our goal was extreme solvation environment or chemical reactivity in complex	
OF ABSTRACT OF PAGES Dr. Ahmed H. Zewail	12. DISTRIBUTION APPROVE 7 13. SUPPLEMENTA 14. ABSTRACT We prop (a) Dynami (b) Dynami (c) New teo In these techniques to ex relate these dyna reactivity. Probin <u>molecular syster</u> 15. SUBJECT TERM	AVAILABILITY STAT For Public R ARY NOTES posed to use this gr cs of elementary st cs of reactions und chniques for direct studies, the basic a amine in real time amics to features o ng and controlling ms. Theoretical stu-	Arlingtor	en VA 22203-1954	g three major a ature, clusterin cal control of r ultrafast laser s on the femtor e the effect of e any model of th colleagues e	SPONSOR/MONITOR'S REPORT NUMBER(S) areas: ng, etc.). eactions yield and channel. (and electron) and molecular bea second time scale. Our goal was extreme solvation environment or chemical reactivity in complex elsewhere were an important part	
a. REPORT b. ABSTRACT c. THIS PAGE 19b. TELEPHONE NUMBER (include	12. DISTRIBUTION APPTOVE 7 13. SUPPLEMENTA 14. ABSTRACT We prop (a) Dynami (b) Dynami (c) New teo In these techniques to ex relate these dyna reactivity. Probin <u>molecular syster</u> 15. SUBJECT TERM	AVAILABILITY STAT For Public R ARY NOTES posed to use this gr cs of elementary st cs of reactions und chniques for direct studies, the basic a amine in real time amics to features o ng and controlling ms. Theoretical stu-	Arlingtor	earch in the following ems. nent (density, temper al changes and chemic the development of the namics and structures anisms and to explore are key to validating d in collaboration with	g three major a ature, clusterin al control of r ultrafast laser s on the femtor e the effect of e any model of th colleagues e	SPONSOR/MONITOR'S REPORT NUMBER(S) areas: ng, etc.). eactions yield and channel. (and electron) and molecular bea second time scale. Our goal was extreme solvation environment or chemical reactivity in complex elsewhere were an important part	
	12. DISTRIBUTION APPTOVE F 13. SUPPLEMENTA 14. ABSTRACT We prop (a) Dynami (b) Dynami (c) New teo In these techniques to ex- relate these dyna- reactivity. Probin- molecular system 15. SUBJECT TERM 16. SECURITY CLA	AVAILABILITY STAT FOR PUBLIC R ARY NOTES Dosed to use this gr cs of elementary st cs of reactions und chniques for direct studies, the basic a amine in real time amics to features o ng and controlling ms. Theoretical studies NS	Arlingtor	earch in the following ems. nent (density, temper al changes and chemic the development of the namics and structures anisms and to explore are key to validating d in collaboration with	g three major a ature, clusterin al control of r ultrafast laser s on the femtor e the effect of e any model of th colleagues e	Areas: ng, etc.). eactions yield and channel. (and electron) and molecular bea second time scale. Our goal was extreme solvation environment or chemical reactivity in complex elsewhere were an important part 19a. NAME OF RESPONSIBLE PERS Dr. Ahmed H. Zewail 19b. TELEPHONE NUMBER (include a	
626.395.6536	12. DISTRIBUTION APPTOVE 7 13. SUPPLEMENTA 14. ABSTRACT We prop (a) Dynami (b) Dynami (c) New tec In these techniques to ex relate these dyna reactivity. Probin molecular syster 15. SUBJECT TERM	AVAILABILITY STAT FOR PUBLIC R ARY NOTES Dosed to use this gr cs of elementary st cs of reactions und chniques for direct studies, the basic a amine in real time amics to features o ng and controlling ms. Theoretical studies NS	Arlingtor	earch in the following ems. nent (density, temper al changes and chemic the development of the namics and structures anisms and to explore are key to validating d in collaboration with	g three major a ature, clusterin al control of r ultrafast laser s on the femtor e the effect of e any model of th colleagues e	SPONSOR/MONITOR'S REPORT NUMBER(S) areas: areas: ng, etc.). reactions yield and channel. (and electron) and molecular bea second time scale. Our goal was extreme solvation environment or chemical reactivity in complex elsewhere were an important part 19a. NAME OF RESPONSIBLE PERS Dr. Ahmed H. Zewail 19b. TELEPHONE NUMBER (include a code)	

Final Performance Report

Air Force Office of Scientific Research

AFOSR Grant No. F49620-98-1-0059

"Femtosecond Dynamics of Chemical Reactions"

Ahmed H. Zewail, Principal Investigator

California Institute of Technology

Division of Chemistry and Chemical Engineering Mail Code 127-72 1200 East California Boulevard Pasadena, California 91125

March 29, 2004

OBJECTIVES

We proposed to use this renewal grant to undertake research in the following three major areas:

(a) dynamics of elementary steps in complex systems.

- (b) dynamics of reactions under extreme environment (density, temperature, clustering, etc.)
- (c) new techniques for direct imaging of structural changes and chemical control of reactions yield and channel.

In these studies, the basic approach is based on the development of ultrafast laser (and electron) and molecular beam techniques to examine in real time the nature of the dynamics and structures on the femtosecond time scale. Our goal was to relate these dynamics to features of bonding and mechanisms and to explore the effect of extreme solvation environment on reactivity. Probing and controlling reactions pathways are key to validating any model of chemical reactivity in complex molecular systems. Theoretical studies in our group and in collaboration with colleagues elsewhere were an important part of this research activity during the entire period of the grant.

STATUS OF EFFORT

We have made significant progress in several areas (please see below and the publication list), including the development of UED for imaging and studying the dynamics of molecular systems with *atomic-scale* resolution, and the dynamics of elementary processes in complex reactions, including ionic systems. The Caltech group has so far published papers in every category, as outlined below.

1

ACCOMPLISHMENTS/NEW FINDINGS

Our accomplishments and new findings are in three areas: (a) fundamental R/D; (b) new technologies and techniques; and (c) education and training of research associates at Caltech.

In the area of fundamental R/D, we have made the following specific accomplishments, highlighted in the summary given below:

(1) Ultrafast Electron Diffraction

With properly timed sequences of ultrafast electron pulses, it is now possible to image complex molecular structures in the four dimensions of space and time with resolutions of 0.01 Å and 1ps, respectively. The new limits of ultrafast electron diffraction (UED) provide the means for the determination of transient molecular structures, including reactive intermediates and non-equilibrium structures of complex energy landscapes. By freezing structures on the ultrafast timescale, we are able to develop concepts that correlate structure with dynamics. Examples include structure-driven radiationless processes, dynamics-driven reaction stereochemistry, pseudorotary transition-state structures, and non-equilibrium structures exhibiting negative temperature, bifurcation, or selective energy localization in bonds. These successes in the studies of complex molecular systems, even without heavy atoms, and the recent development of a new machine devoted to structures in the condensed phase, establish UED as a powerful method for mapping out temporally changing molecular structures in chemistry, and potentially, in biology. A recent review* highlights the advances made at Caltech, with emphasis on the principles of UED, its evolution through four generations of instrumentation (UED-1 to UED-4) and its diverse applications. [*Ultrafast Electron Diffraction (UED) A New Development for the 4D Determination of Tansient Molecular Structures, Ramesh Srinivasan, Vladimir A. Lobastov, Chong-Yu Ruan, and A. H.

2

Zewail, Review Article, *Helvetica Chimica Acta.*, **86**, 1761-1838 June Special Issue, 1 (2003).]

(2) Microscopic Solvation

Ultrafast dissociation and recombination dynamics of $(O_2)_n^-$, n = 3-10 was studied using femtosecond, time-resolved photoelectron spectroscopy. The observed transients of nascent fragment anions, following 800 nm fs pulse excitation, exhibit a biexponential rise with two distinct time constants. The time constants, which vary with the number of solvent O_2 molecules, clearly show the solvation effect in two different dissociation pathways. Consistent with the bifurcation picture in the preceding paper, the direct subpicosecond dissociation ($\tau_1 = 110 - 620$ fs, depending on *n*) is governed by electron recombination and kinematics of the half-collision. The second pathway is indirect $(\tau_2 = 0.7 - 8.0 \text{ ps}, \text{ for } O_6^- \text{ to } O_{20}^-)$ and controlled by intramolecular vibrational-energy redistribution. In the solvent cage, only O_{16}^- , O_{18}^- , and O_{20}^- show the reformation of the bond, with the caging time constant decreasing from 4 ps for the first two to 2 ps for the latter. This caging through ion-induced dipole interaction is then followed by vibrational relaxation on the time scale of 12 to 3 ps, for O_{16}^- to O_{20}^- . The time scale for the initial direct caging is two to five times slower than that previously observed for diatoms, neutral, or ionic, in van der Waals clusters. We showed that this initial slower caging is due to the reorientation of O_2^- and O_2 to acquire a proper geometry for $O_4^$ bond reformation. In these finite-sized homogeneous clusters, we compared theory with experiment. We also found a correlation between the vertical detachment energy and $n^{-1/3}$, for *n* in the range of 2-10, which allow for a connection between the mesoscopic structures and a bulk-type dielectric continuum, with an effective dielectric constant. These types of studies are critical to our understanding of energy disposal in complex systems.* [*Femtosecond dynamics of solvated oxygen anions. II. Nature of

3/29/04

3

dissociation and caging in finite-sized clusters, Nam Joon Kim, D. Hern Paik, and A. H. Zewail, J. Chem. Phys. **118**, 6930 (2003).]

Finally, the Caltech group currently has close to 30 visiting associates, post-doctoral fellows, graduate students and undergraduate students. The training and education of a new generation of scientists and technologists in these areas has been extremely profitable, as evident by the leading positions these associates acquire in academic institutions and in the industrial sector.

PERSONNEL SUPPORTED

Several graduate students and post-doctoral research fellows have been involved (supported, partially supported, or having their own fellowships) in this research. Over the years, many from this group have been successful in obtaining leading positions, and the list includes:

- Dr. P. Felker (presently on the faculty at UCLA)
- Dr. M. Gruebele (presently on the faculty at the University of Illinois at Urbana-Champaign)
- Dr. M. Dantus (presently on the faculty at Michigan State University)
- Dr. W. Warren (presently on the faculty at Princeton University)
- Dr. N. Scherer (presently on the faculty at the University of Chicago)
- Dr. J. Perry (presently on the faculty at Georgia Tech)
- Dr. D. Millar (presently on the faculty at Scripps)
- Dr. J. Knee (presently on the faculty at Wesleyan University)
- Dr. R. Bowman (presently on the faculty at Colgate University)

Dr. L. Bañares (presently on the faculty at Complutense de Madrid University)

- Dr. G. Roberts (presently at the University of Cambridge)
- Dr. M. Janssen (presently at the University of Amsterdam)
- Dr. M. Rosker (presently at Rockwell)
- Dr. T. Rose (presently at Aerospace Corporation)
- Dr. T. Baumert (presently on the faculty at University of Kassell)
- Dr. J. Cao (presently on the faculty at Florida State University)
- Dr. A. Douhal (presently on the faculty at Universidad de

Castilla-La Mancha

Dr. Eric Wei-Guang Diau (presently on the faculty at National Chiao-Tung University, Taiwan)

- Dr. Arnulf Materny (presently on the faculty of the International University Bremen)
- Dr. Boyd Goodson (presently on the faculty at Southern Illinois U.)
- Dr. Hyotcherl Ihee (presently on the faculty at KAIST, Korea)
- Dr. Nam Joon Kim (presently on the faculty at Chungbuk National University, Korea)
- Dr. Carsten Kötting (presently on the faculty at Ruhr-Universität Bochum, Germany)
- Dr. Jorge Peon-Peralta (presently on the faculty at the University of Mexico)
- Dr. Xiaogang Qu (presently on the faculty of the Chinese Academy of Sciences)
- Dr. Theis Sølling (presently at the University of Copenhagen, Denmark)
- Dr. Dongping Zhong (presently on the faculty at Ohio State University)
- Dr. Shouzong Zou (presently on the faculty at Miami U. in Ohio)
- Dr. Samir Pal (presently on the faculty of the Bose Institute in Calcutta in the fall of 2003)
- Dr. Hans-Christian Becker (presently on the faculty of Uppsala University, Sweden)
- Dr. Qing-Bin Lu (presently on the faculty at the University of Waterloo, Canada)
- Dr. Chong-Yu Ruan (presently on the faculty at Michigan State University)

At Caltech, current postdoctoral research fellows are: S. Baskin, M. D'Orsogna, A.

Kamal, V. Lobastov, S.T. Park, C.-Y. Ruan, F. Vigliotti, C. Wan, Y. Wang, T. Xia, S. Xu, and L.

Zhao. Current graduate students are: S. Chen, F. J. Feenstra, I.-R. Lee, H. Paik, R. Srinivasan,

D. Yang, and L. Zhang.

In addition, we have had collaborative efforts with Professors J. Barton, F. Anson, W.

Goddard, V. McKoy, R. Roberts, Z.-G. Wang (Caltech); Professor K. Houk (UCLA); Professor

A. Scala (Worcester Polytechnic Institute, Massachusetts); Professor J. Casanova (California

State University, Los Angeles); and Professor Gustav Gerber (University of Würzburg).

PUBLICATIONS - Articles (selected publications)

Direct Determination of Hydrogen-Bonded Structures in Resonant and Tautomeric Reactions Using Ultrafast Electron Diffraction

Ramesh Srinivasan, Jonathan S. Feenstra, Sang Tae Park, Shoujun Xu, and A. H. Zewail J. Am. Chem. Soc., **126**, 2266-2267 (2004)

Ultrafast Electron Diffraction and Transient Complex Structures: From Gas Phase to Crystallography

A. H. Zewail *Femtochemistry and Femtobiology: Ultrafast Events in Molecular Science,* Ed. M. Martin and J.T. Hynes, Elsevier, (2004)

Ultrafast Electron Diffraction. From the Gas Phase to the Condensed Phase with Picosecond and Femtosecond Resolution

Vladimir A. Lobastov, Ramesh Srinivasan, Franco Vigliotti, Chong-Yu Ruan, Jonathan S. Feenstra, Songye Chen, Sang T. Park, Shoujun Xu, and A. H. Zewail *Springer Series in Optical Sciences*, Ed. Krausz, F. (2003).

Femtosecond Dynamics of Solvated Oxygen Anions: I. Bifurcated Electron Transfer Dynamics Probed by Photoelectron Spectroscopy

D. Hern Paik, Nam Joon Kim, and A. H. Zewail J. Chem. Phys. 118, 6923 (2003)

Femtosecond Dynamics of Solvated Oxygen Anions: II. Nature of Dissociation and Caging in Finite-Sized Clusters

Nam Joon Kim, D. Hern Paik, and A. H. Zewail J. Chem. Phys. 118, 6930 (2003)

Ultrafast Electron Diffraction: Complex Landscapes of Molecular Structures in Thermal and Light-Mediated Reactions

Boyd M. Goodson, Chong-Yu Ruan, Vladimir A. Lobastov, Ramesh Srinivasan, and A. H. Zewail

Chem. Phys. Lett, 374, 417-424 (2003)

Ultrafast Electron Diffraction (UED) A New Development for the 4D Determination of Transient Molecular Structures

Ramesh Srinivasan, Vladimir A. Lobastov, Chong-Yu Ruan, and A. H. Zewail Review Article

Helvetica Chimica Acta. June Special Issue, 1 (2003)

Orientation Dynamics and Molecular Structures from Gas Phase to Condensed Media. J.S. Baskin and A.H. Zewail

in: Femtochemistry and Femtobiology: Ultrafast Dynamics in Molecular Science ed. A. Douhal and J. Santamaria (World Scientific, Singapore, 2002) Ultrafast Electron Diffraction of Transient Cyclopentadienyl Radical: A Dynamic Pseudorotary Structure

H. Ihee, J.S. Feenstra, J. Cao, and A.H. Zewail *Chem. Phys. Lett.* **353**, 325-334 (2002)

Ultrafast Electron Diffraction and Structural Dynamics: Transient Intermediates in the Elimination Reaction of $C_2F_4I_2$

H. Ihee, B.M. Goodson, R. Srinivasan, V.A. Lobastov, and A.H. Zewail *J. Phys. Chem. A*, **106**, 4087 (2002)

Kinetics Modeling of Dynamics: The Case of Femtosecond-Activated Direct Reactions K.B. Møller and A.H. Zewail *Chem. Phys. Lett.* **351**, 281-288 (2002)

Coherent Dynamics in Complex Elimination Reactions: Experimental and Theoretical Femtochemistry of 1,3-Dibromopropane and Related Systems

C. Kötting, Eric W.-G. Diau, T.I. Sølling and A.H. Zewail J. Phys. Chem. A, 106, 7530 (2002)

Chemistry at the Uncertainty Limit

A.H. Zewail Angew. Chem. 40/23, 4371 (2001) Angew. Chem. Int. Ed. (German) 113/23, 4501 (2001)

Ultrafast Diffraction of Transient Molecular Structures in Radiationless Transitions V.A. Lobastov, R. Srinivasan, B.M. Goodson, C.-Y. Ruan, J.S. Feenstra and A.H. Zewail *J. Phys. Chem. A.* **105**, 11159 (2001)

Femtochemistry of Norrish Type-I Reactions: IV. Highly-Excited Ketones, Experimental T.I. Sølling, E. W.-G. Diau, C. Kötting, S. De Feyter, and A.H. Zewail *Chem. Phys. Chem.* 3, 79-97 (2002)

Direct observation of resonance motion in complex elimination reactions: Femtosecond coherent dynamics in reduced space.

C. Kötting, E. W.-G. Diau, J.E. Baldwin, and A.H. Zewail J. Phys. Chem. A 105, 1677 (2001)

Femtochemistry of Norrish Type-I Reactions: I. Experimental and Theoretical Studies of Acetone and Related Ketones on the S₁Surface

E. W.-G. Diau, C. Kötting, and A.H. Zewail *Chem. Phys. Chem.* **2**, No. 5, 273 (2001)

 CF_2XCF_2X and CF_2SCF_2 .•radicals (X = Cl, Br, I): Ab Initio and DFT Studies and Comparisons with Experiments

H. Ihee, J. Kua, W.A. Goddard III, and A.H. Zewail J. Phys. Chem. A 105, 3623 (2001)

Direct Imaging of Transient Molecular Structures with Ultrafast Diffraction H. Ihee, V. Lobastov, U. Gomez, B. Goodson, R. Srinivasan, C. -Y. Ruan, and A.H. Zewail *Science* **291**, 385 (2001)

Femtochemistry--Atomic-Scale Dynamics of the Chemical Bond using Ultrafast Lasers, Les Prix Nobel, The Nobel Prizes, Nobel Biography, "A Personal Voyage Through Time" and Nobel Address

A.H. Zewail

Almquist & Wiksell International, Stockholm (2000) - Book Chapter; *Angewandt Chemie*,, Invited, International Edition, **39**, 2586-2631 (2000); German Edition, **112**, 2688-2738 (2000)

Femtochemistry – Atomic-Scale Dynamics of the Chemical Bond

H. Zewail

J. Phys. Chem. – Feature Article (Nobel Lecture), 104, 5660 (2000)

INTERACTIONS/TRANSITIONS

Participation/Presentations at Meetings and Conferences (Examples)

- Keynote Address, Linus Pauling Centenary, Oregon State University, Corvallis, February 28, 2001
- Schrödinger's Wave Mechanics (75th) Celebration Lecture, University of Zürich, Switzerland, April 24, 2001
- George B. Kistiakowsky Lecture, Harvard University, Cambridge, Massachusetts, April 30, 2001

The National Institutes of Health Director's Lecture, Bethesda, Maryland, May 4, 2001

National Science Foundation Distinguished Lecture (MPS), Arlington, Virginia, May 7, 2001

- Plenary Opening Lecture, Joint CLEO/QELS 2001, Conference on Lasers and Electro-Optics/Quantum Electronics and Laser Science Conference, Baltimore, Maryland, May 8, 2001
- Inauguration of Lectures of Nobel Prize Winners, Public Conference, Novartis & University of Basel, Basel, Switzerland, June 12, 2001
- Inauguration of La Premiere Conference Jean Perrin, Collége de France, Paris, France, June 18, 2001

Albert Einstein Lecture, New Delhi, India (2002)

Keynote Lecture, NanoBioScience Institute, South Korea (2002)

Nobel Youth Lecture, Royal Swedish Academy, Stockholm (2002)

- U Thant Distinguished Lecture Series, United Nations University, Tokyo, Japan (2003)
- Republic of Korea Visit: Meeting, Minister of Commerce, Industry & Energy, Seoul, April 18, 2003; Meeting, Minister of Health & Welfare, Seoul, April 17, 2003; Meeting (with presentation) CEO and two Vice Chairmen of Samsung Co., Seoul, April 17, 2003
- Opening Lecture; "Ultrafast Dynamics with Diffraction and Mass Spectrometry"; Air Force Office of Scientific Research Meeting; Shelter Pointe Hotel, (San Diego, California), May 18, 2003
- Keynote Address; "Voyage of Discoveries"; California State Science Fair; California Science Center, (Los Angeles, California) May 19, 2003
- Opening Lecture; "Biostructures in Space and Time"; Frontiers in Chemistry, Georgia Tech College of Sciences, (Atlanta, Georgia) May 23, 2003
- Opening Lecture; "Energy and Our World", Swedish Academy of Sciences Conference, (Stockholm, Sweden), March 9, 2004

Consultative and Advisory Functions (Examples)

Editor, Chemical Physics Letters Advisory Editorial Board, Chemical Physics Editorial Board of Advisors, Laser Focus World Editorial Board, The Chemical Intelligencer Advisory Board, American Men and Women of Science Advisory Board, World Scientific Advisory Board of the Laser Facility, University of Pennsylvania Advisory Board, The University of Basel, Switzerland Editorial Advisory Board, *Chemical Reviews* Advisory Board, *Angewandte Chemie* (Chem. Phys. Chem.) Editorial Board, Cambridge University Press Series

Transitions

Throughout the development of ultrafast imaging techniques we have exchanged the new findings on the bombardment of CCD's with electrons with the Jet Propulsion Laboratory, where these CCD technologies are an essential part of the Space Program. We have also benefited greatly from their expertise in this area. The development of UED represents major advances in the technology of ultrafast electrons, lasers, and computers.

NEW DISCOVERIES, INVENTIONS, OR PATENT DISCLOSURES

During the period of the grant we have made one major development and some new discoveries. In a paper published in *Science*, we have developed ultrafast electron diffraction to a new level. With this apparatus, for the first time, we are able to clock a change of chemical structure of *intermediates* with one picosecond resolution, and with a spatial resolution of 0.01Å. As described in a publication to appear soon in *Science*, we believe that a breakthrough in this field has been made. We are now able to perform diffraction of crystals and materials on the nanometer scale.

The discovery of a new ultrafast phenomenon in mesoscopic systems is novel and significant. In a series of publications in the journal of *Chemical Physics*, we reported on studies of oxygen anion clusters with first and second solvation shells. These are important

mesoscopic systems that are highly reactive in chemical and biological (O_2^-) systems. Other

discoveries are reported in the references given.

HONORS/AWARDS (INCOMPLETE)

The Nobel Prize in Chemistry

The Ahmed Zewail Fellowships, University of Pennsylvania Other awards are listed on the curriculum vitae, and on the web page at www.its.caltech.edu/~femto/zewail.htm

D.Sc., h.c., (honorary degree) Katholieke Universiteit, Leuven, Belgium (1997)

D.Sc., h.c., (honorary degree) University of Pennsylvania, U.S.A. (1997)

D.Sc., h.c., (honorary degree) Université de Lausanne, Switzerland (1997)

D.U., h.c., (honorary degree) Swinburne University, Australia (1998)

Doctoris in Scientia, D.Sc., h.c. (honorary degree) University of New Brunswick, Canada (2000)

Dottore *honoris causa*, D., h.c. (honorary degree) University of Rome "La Sapienza"(2000)

Doctor *honoris causa*, D., h.c. (honorary degree) Université de Liège, Belgium (2000)

Doctor *honoris causa*, D., h.c. (honorary degree) Heriot-Watt University, Scotland (2002)

D.Ph., h.c. (honorary degree) Lund University, Sweden (2003)

Member:

National Academy of Sciences

Pontifical Academy of Sciences

American Philosophical Society

The Royal Danish Academy of Sciences & Letters

American Academy of Arts and Sciences

American Philosophical Society

Académie Européenne des Sciences, des Arts et des Lettres, France

American Physical Society

American Association for the Advancement of Science

Third World Academy of Sciences, Italy

American Chemical Society

Inter-American Photochemical Society

Sigma Xi Society

Royal Society of London

Russian Academy of Sciences

Royal Swedish Academy of Sciences